# ROOF BOLTING IN ALABAMA COAL MINES AND IRON-ORE MINES

BY H. C. YOUNG

* * * * * * * * * **Information Circular 7678**

UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary
BUREAU OF MINES
J. J. Forbes, Director

---

Work on manuscript completed November 1953. The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is made: "Reprinted from Bureau of Mines Information Circular 7678."

March 1954

# ROOF BOLTING IN ALABAMA COAL MINES AND IRON-ORE MINES

by

H. C. Young[1]

## CONTENTS

| | Page |
|---|---|
| Introduction | 1 |
| Acknowledgment | 1 |
| General information | 2 |
| History | 4 |
| Coal-mine installations | 5 |
| Ore-mine installations | 9 |
| Failures of bolted roof | 11 |
| Accidents | 12 |
| Conclusions | 13 |

## TABLES

1. Tonnage and roof-bolt data, 5 years, May 1, 1948 - May 1, 1953 .... 14
2. Tonnage and roof-bolt data as of May 1, 1953 .... 14
3. Fatalities and fatality rates, 5 years, May 1, 1948 - May 1, 1953 .... 14
4. Analysis of roof-fall fatalities .... 15

## ILLUSTRATIONS

| Fig. | | Follows page |
|---|---|---|
| 1. | Steel timbering as used before roof bolting (ore mines) | 4 |
| 2. | Wood timbering as used before roof bolting (ore mines) | 4 |
| 3. | Difficulty in supporting heavy roof with 12 inch x 20-foot wood collars (ore mines) | 4 |
| 4. | Difficulty in supporting heavy roof with timbers (Concord coal mine) | 4 |
| 5. | Advantages and improved roof after bolting (Concord coal mine) | 4 |

---

[1] Roof-bolt technician, Accident Prevention and Health Division, Region VII, Bureau of Mines, Birmingham, Ala.

Information Circular 7678

ILLUSTRATIONS (Cont.)

| Fig. | | Follows page |
|---|---|---|
| 6. | Rooms driven 30 feet in width and roof bolted (coal mine) | 4 |
| 7. | Entries 15 feet wide, top brushed and roof bolted (coal mine) | 6 |
| 8. | Coal seam held intact with roof bolts in a combination coal and clay mine | 6 |
| 9. | Rooms 28 feet wide; roof bolting in a combination coal and clay mine | 6 |
| 10. | Combination roof bolting and timbering plan for 30-foot rooms (coal mine) | 6 |
| 11. | Roof bolts used in conjunction with three-piece timber sets (coal mine) | 6 |
| 12. | Posts used in conjunction with roof bolts in 35-foot rooms (coal mine) | 6 |
| 13. | Combination bolting and timbering plan for rooms driven 42 feet in width (coal mine) | 6 |
| 14. | Combination bolting and timbering plan for rooms driven 30 feet in width (coal mine) | 6 |
| 15. | Roof and rib bolting along old haulage slope (coal mine) | 8 |
| 16. | Roof bolts used in conjunction with timbering in pillar extraction (coal mine) | 8 |
| 17. | Place ready to be bolted with safety timbers in place | 8 |
| 18. | Roof is thoroughly tested before beginning to bolt | 8 |
| 19. | Permissible dust collector is placed where hole is to be drilled | 8 |
| 20. | Roof bolter maintains firm grasp on stoper as hole is drilled | 8 |
| 21. | Roof bolter holds onto drill steel as it is withdrawn | 8 |
| 22. | As hole is completed, roof bolt is inserted | 8 |
| 23. | Roof bolt is driven onto wedge with stoper for 10 seconds | 8 |
| 24. | Impact wrench is tested for correct rotation | 8 |
| 25. | Nuts are tightened on bolt until bearing plate begins to cup | 8 |
| 26. | A place after it has been bolted | 8 |
| 27. | Mobile air compressors with all necessary tools and supplies | 8 |
| 28. | Roof bolts are also used in hanging ventilation curtains. | 8 |
| 29. | Combination of vertical and angle bolting in the ore mines | 10 |
| 30. | Vertical bolting in ore mines | 10 |
| 31. | Drilling the face under bolted roof in ore mine | 10 |
| 32. | Loading ore under bolted roof | 10 |
| 33. | Old and new methods of roof support in an ore mine | 10 |
| 34. | Heavy roof at a wide intersection supported with bolts (ore mine | 10 |
| 35. | Working place being roof-bolted in an ore mine | 10 |

## INTRODUCTION

This paper deals with roof bolting in Alabama coal mines and iron-ore mines from the time it was introduced in early May 1948 to May 1, 1953, a 5-year period. The Tennessee Coal & Iron Division of the United States Steel Corp. began systematic roof bolting in early May 1948 in a coal mine and in an iron-ore mine, which had some of the poorest roof conditions in the Alabama mines. After the efficiency of roof bolting had been proved by the Tennessee Co. it was gradually adopted by other companies throughout the State, until in May 1953 approximately 53 percent of Alabama's total coal production and 100 percent of Alabama's total iron-ore production, mined underground, was being produced from roof-bolted areas. Statistics in this report will show the advancement made in roof bolting in the 5 years and also the amount of roof bolting that was being done as of May 1, 1953.

Significant progress has been made in the coal and iron-ore mines of Alabama in reducing the roof-fall fatality rates during the past several years by adopting systematic roof bolting. The groundwork was laid through successful experiments early in 1948 by the Tennessee Coal & Iron Division of the United States Steel Corp. in cooperation with the Federal Bureau of Mines. This experimental work was based upon the previous experience of the St. Joseph Lead Co.[2] in its Southeastern Missouri mines.

Roof bolting is a method of mine roof support wherein the roof rock is stabilized and reinforced by anchoring steel rods inserted through drill holes, as opposed to permitting this rock to flex to failure and then placing wooden or steel supports to prevent failed broken rock from flowing into the mine openings.

The purpose of this paper is to evaluate this development and to document the details of the steps that brought it about in the hope that other mining districts may derive similar advantages.

## ACKNOWLEDGMENT

The author gratefully acknowledges the cooperation and assistance given by officials of the various mining firms using roof bolts and the Alabama Department of Industrial Relations in furnishing photographs, data, and information necessary for this paper. Photographs used in the publication were furnished by the Tennessee Coal & Iron Division of the United States Steel Corp.

---

[2] Thomas, E., Barry, A. J., and Metcalf, A., Suspension Roof Support, Progress Report I.: Bureau of Mines Inf. Circ. 7533, 1949, 13 pp.

Original from THE OHIO STATE UNIVERSITY

# GENERAL INFORMATION

Alabama[3] coal fields occupy the north-central part of the State, with Birmingham virtually in the center of the active fields. The coal measures underlie virtually all of 11 counties. Portions of other counties have considerable coal that is not being mined. The Pottsville, or coal-bearing, formation of Alabama is divided into four fields, named, in order of their size and productiveness, the Warrior, Cahaba, Coosa, and Plateau. The Coosa field is the easternmost of the Pottsville area; the Cahaba field is a few miles west of the Coosa field; the Warrior field is that area of the Pottsville that extends from Birmingham and Murphrees Valleys to the west side of the State and southwestward an unknown distance under the deposits of the coastal plain; the Plateau field is composed of a number of separate areas in the northeastern part of the State, extending westward to Monte Sano in Madison County and just east of Huntsville and including Blount Mountain, Lookout Mountain, Sand Mountain, and a number of hilltop areas in Jackson, Marshall, and Madison Counties. The Coosa and Cahaba fields are relatively narrow structural troughs or synclines faulted along their southeast sides. The rocks dip southwestward from the northwest side, and the basal strata reach great depths in the deepest parts of the troughs. The Warrior field occupies a broad, relatively shallow basin.

The coal beds are separated by shale and sandstone intermixed but in some cases by massive sandstone and in others by conglomerates, some of them very thick.

The Warrior Basin lies northwest of and adjacent to Birmingham. The greater part of the coal mined in Alabama comes from this basin, of which the Brookwood, Pratt, Mary Lee, and Black Creek are the four principal coal beds.

Most coal mines in Alabama are opened by drifts or slopes and the rest by shafts. The overburden ranges from a few feet at the outcrop to about 800 feet from the lowest workings. The coal seams now worked range from 2 feet to 12 feet in thickness. The room-and-pillar system of mining is employed generally, but a few medium-size mines use a modified-longwall system in mining thin seams. Entry widths range between 8 and 25 feet. Rooms 16 to 45 feet in width are driven to various depths, ranging up to 300 feet. Coal is loaded by hand directly into mine cars in most small mines. Coal is loaded onto shaker or chain conveyors in the other hand-loading mines. The larger mines are 100 percent mechanized. Continuous-mining machines are used in sections of two mines.

The roof throughout the coal mines consists of shales and sandstones. Shale predominates as the immediate roof, but in a few mines and in sections of a few other mines sandstone is the immediate roof. The shale is stratified in some areas and crossbedded in other areas and ranges from a few inches to 30 feet or more in thickness. At times and at various levels it is interstratified with sandstone. The sandstone strata vary from thick bedded or massive formation to thin, laminated formation. Draw slate, ranging to about 40 inches in thickness, is present in many mines.

The roof rocks throughout the coal fields vary from solid and self-supporting to very fragile and weak. The roof stratum of all mines is embedded to some extent with coal streaks, rider seams, slips, pots, faults, horsebacks, and carbonaceous shale. The poorest roof conditions are generally found where these conditions are prevalent and where coal is mined under shallow cover or near the crop and where the strata is saturated with water. Much of the roof requires support soon after exposure or failures occur.

---

[3] Division of Safety and Inspection, Department of Industrial Relations, Annual Statistical Report: Birmingham, Ala., Fiscal Year, 1951-52.

Original from THE OHIO STATE UNIVERSITY

The Birmingham district of Alabama, which ranks as one of the important iron and steel centers of the United States, is generally considered to include the iron and coal mines tributary to the blast furnaces of Birmingham. The Birmingham district holds large deposits of red hematite, coal, and flux and extends from Springville, Ala., on the northeast to below Vance, Ala., on the southwest. Although the belt is about 75 miles long, only a relatively small part is now productive. Most of the mining is confined to a section about 10 miles long between Birmingham and Bessemer, within which lie the so-called merchantable ores.4/ The ores lie as bedded deposits in Red Mountain, which extends northeast and southwest between Birmingham and Bessemer and beyond, although the most important part of the district is between the cities named.5/ The Clinton formation in which the ore seams occur is of Silurian age and ranges from 500 feet in thickness at the northeast end of the Birmingham Basin to 30 feet at the southwest end.6/ There are 3 ore beds in the Clinton formation, but only 2 are now being worked, the Big Seam and the Irondale. The ore beds from the top down are the Ida, the Big Seam, and the Irondale The ore from the Ida bed is of poor grade and not suitable for making iron under present conditions. At the time of this writing 1 ore mine was being operated in the Irondale Seam and 13 in the Big Seam. The Big Seam lies roughly 20 to 50 feet below the Ida and is the main source of ore. It varies from 16 to 30 feet in thickness, with rarely more than 12 feet of good ore; in most places only 7 to 10 feet is mined. The Big Seam usually consists of two benches, an upper and lower bench. The upper bench is higher grade and is the principal source of ore. The lower bench is more siliceous and has been mined only sparingly. Below the Big Seam, but usually closely associated with it, lies the Irondale seam of variable thickness. The thickness of the several seams as given will vary considerably in different sections. At places the 2 benches of the Big Seam will be found separated by as much as 3 feet or more of shale.7/ The Big Seam and the Irondale bed outcrop along Red Mountain and dip southeast. The pitch of the seams ranges from about 10° to 50°. All of the mines, except one, are opened by slopes developed from the outcrop. One mine is opened by a vertical shaft of 6 compartments 1,250 feet in depth through rock strata to intercept the Big Seam ore bed. The lengths of the slopes range between 3,000 and 6,600 feet. Maximum cover is about 1,800 feet. The room-and-pillar system of mining is followed. Entries are driven in sets of 2, 3, or 4 and range between 14 feet and 30 feet in width. Rooms 20 feet to 30 feet in width are driven to various depths ranging up to 400 feet. The slabbing method is most generally followed in robbing pillars. All ore is loaded mechanically either with loading machines or scraper loaders.

The roof overlying the ore beds consists mainly of bedded ferruginous and nonferruginous sandstone interbedded with layers of hard sandy shale. In some areas a tough cap rock or draw rock (partly ore and rock) ranging from a few inches to 36 inches in thickness separated the ore seams and main roof. The roof strata ranges from thin laminations to layers several feet in thickness, and in some cases is of massive formation. The roof at certain locations has slips, pots, rolls, faults, and other planes of weakness. At some locations the roof strata is tough, strong, and generally self supporting, however, most of the strata at other localities are structurally weak and have a tendency to break away in flat pieces and tabular slabs, and fall progressively unless supported.

---

4/ Lee, Oscar, Ganrud, B. W., and Devaney, F. D., Magnetic Concentrations of Iron Ores of Alabama: Bureau of Mines Bull. 278, 1927, 75 pp.

5/ Burchard, E. F., Butts, Charles, Iron Ores, Fuels and Fluxes of Birmingham District, Ala.: Geol. Survey Bull. 400, 1910, 204 pp.

6/ Thoenen, J. R., and Reed, Avery H., Jr., The Future of Birmingham Red Iron Ore, Jefferson County, Ala.: Bureau of Mines Rept. of Investigations 4988, 1953, 71 pp.

7/ See footnote 6.

## HISTORY

The pioneering work on roof bolting in Alabama was done by the Tennessee Coal & Iron Division of the United States Steel Corp. in the Concord coal mine and No. 4 Muscoda ore mine. To quote E. H. Stevens,[8] project engineer, Tennessee Coal & Iron Division, United States Steel Corp.:

> The Tennessee Company became interested in the possible application of bolted roof support through information furnished by the United States Bureau of Mines, and we believe that the Roof-Control Section of the Bureau deserves considerable credit for its promotional activities. Inspection trips by our personnel to the St. Joseph Lead Company, where roof bolting has been successfully employed for a number of years, led to the acceptance of the bolting principle and we began experimental work in May of 1948 to determine the best application for our coal mines and iron ore mines. Roof bolting has meant a great deal to our company. Possibly a description of our conditions prior to roof bolting will illustrate this point. In our coal mines the standard timbering system specified timbers on a maximum of 4-foot centers, but in practice roof conditions in many sections necessitated closer placement and the use of extra heavy timbering with cross collars and logging. In one mine, bad roof required the use of 5-inch H-beams for legs and 15-inch I-beams for cross collars along entries and 4-inch H-beam cross-collars as close as 2-foot centers for face timbering.
>
> In the ore mines with about 1,600 feet of cover the systematic conventional method required the use of 12-inch by 12-inch by 20-foot wood timbers or 12-inch I-beam collars set on 8-inch H-beam legs along entries and 12-inch round posts or cross-collars in slopes or rooms. A seven-man timber crew was required. Specifications required permanent cross-collars on a maximum of 8-foot centers, but in most workings bad top necessitated additional sets. Blast damage was commonplace; often a face-shot would dislodge 5 or 6 cross-collars, which meant that not only was it necessary to reset and reblock the timbers, but also that the roof would loosen and much quarrying or barring down was required before a place was made safe for mining operations. Major falls would "ride out" permanent timbers for distances up to 100 feet along entries. Such roof conditions require good timbering.

Some of the systems of roof control as used before roof bolting was adopted in the ore mines are shown in figures 1, 2, and 3. Figure 1 is a picture of three-piece steel-timber sets, and figure 2 a picture of three-piece wooden-timber sets used along haulageways. Figure 3 shows 12- by 12-inch wooden cross collars used along entries and rooms which were supported on either steel or wooden legs.

When roof bolting was introduced in the Concord mine, the mine was relatively new, and only entry development was being done. The roof at the time was very poor and consisted of very weak carbonaceous shale ranging from 6 to 30 inches in thickness. The shale was overlain with sandstone, which contained angular and vertical clevage planes. The same type of roof exists today, except that the carbonaceous shale in some areas ranges up to as much as 8 feet in thickness. After roof bolting was tried on a small scale for some time in the Concord mine, the management became convinced of the practicability of using bolts to reinforce mine roof. The practicability of roof bolting having been proved, it was then extended gradually to all sections of the mine and introduced into other coal mines and ore mines operated by the company. As of April 1, 1953, the Concord mine was being roof bolted 100 percent in producing an average of 7,474 tons of coal, tipple weight, per day. The average number of bolts used each day was 2,172. Figure 4 shows the

---

[8] Stevens, E. H., Successful Roof Bolting in Alabama, Coal Mine Modernization, 1950 Year Book.

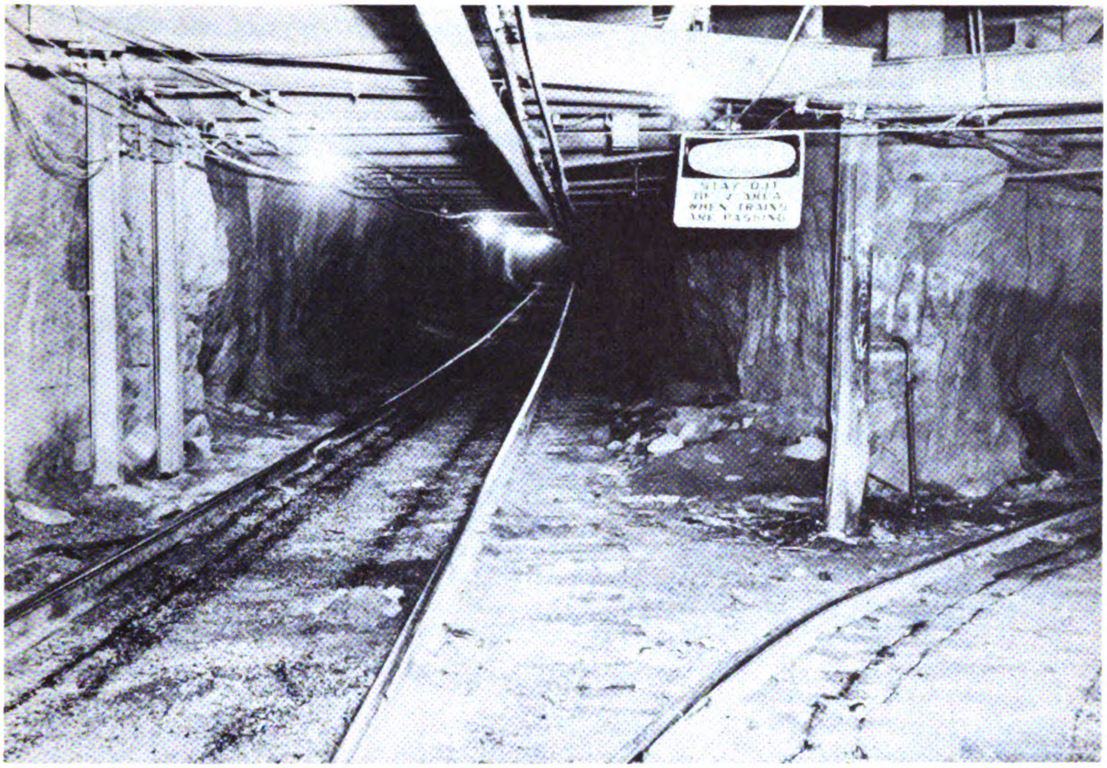


Figure 1. - Steel timbering as used before roof bolting (ore mines).

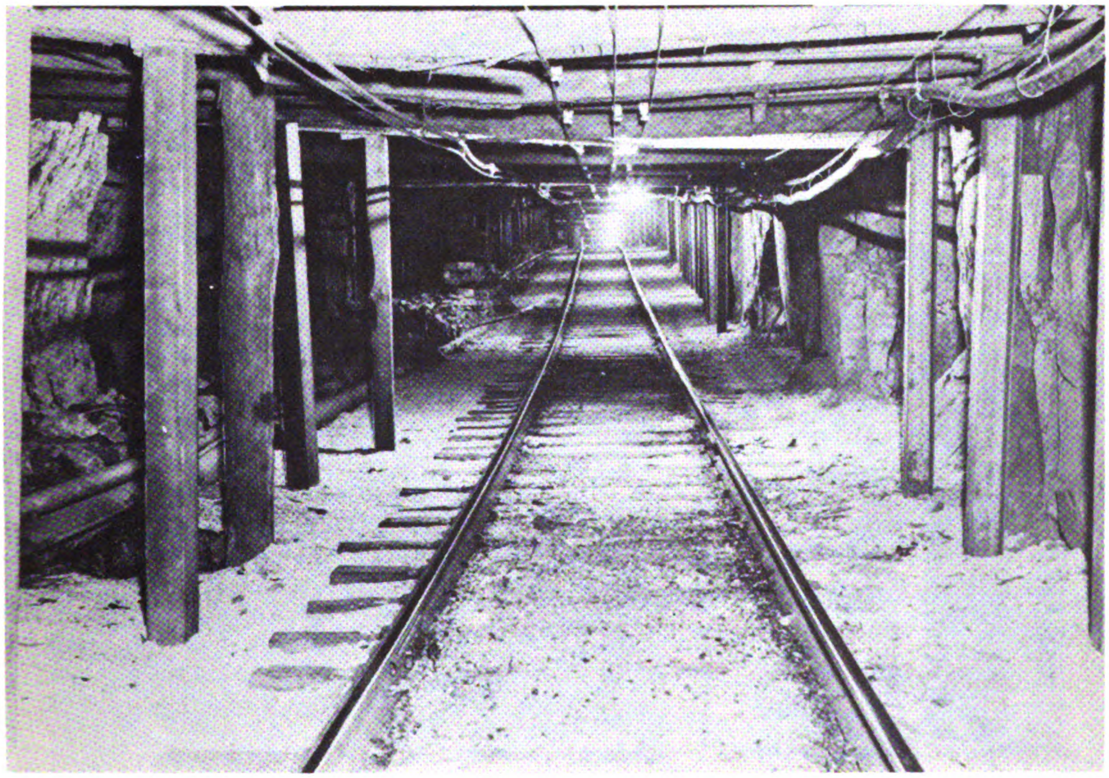


Figure 2. - Wood timbering as used before roof bolting (ore mines).

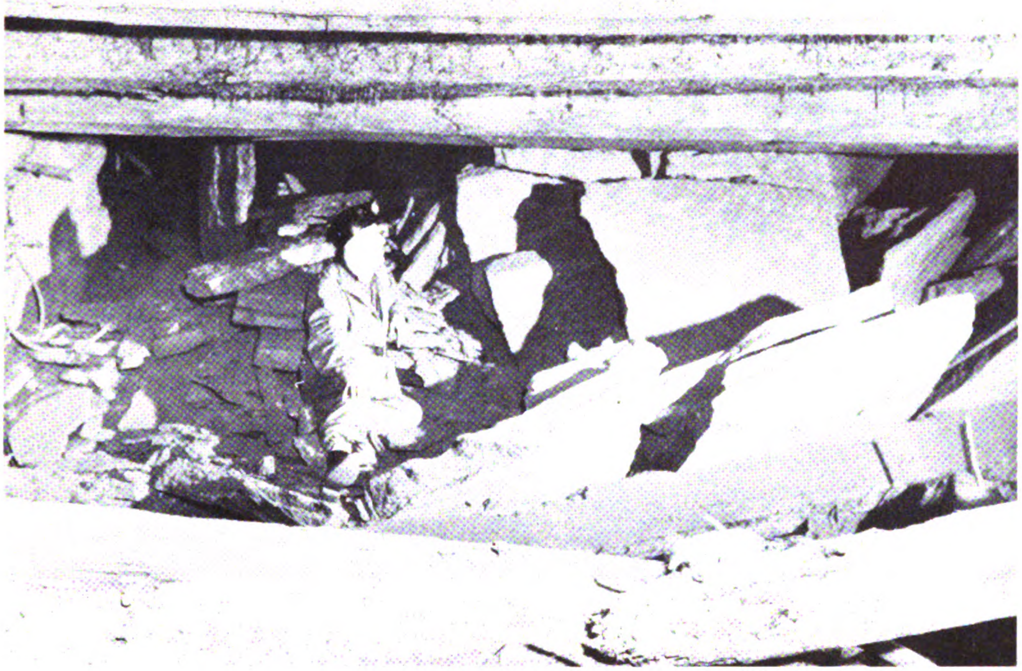


Figure 3. - Difficulty in supporting heavy roof with 12 inch x 20 foot wood collars (ore mines)

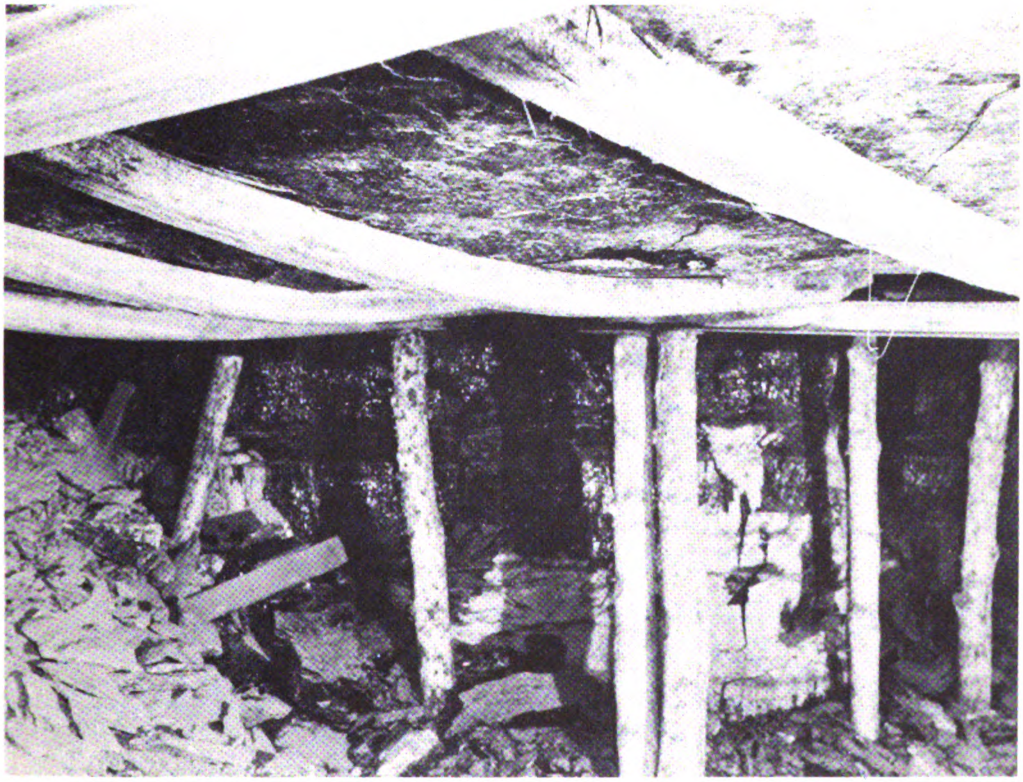


Figure 4. - Difficulty in supporting heavy roof with timbers (Concord coal mine).

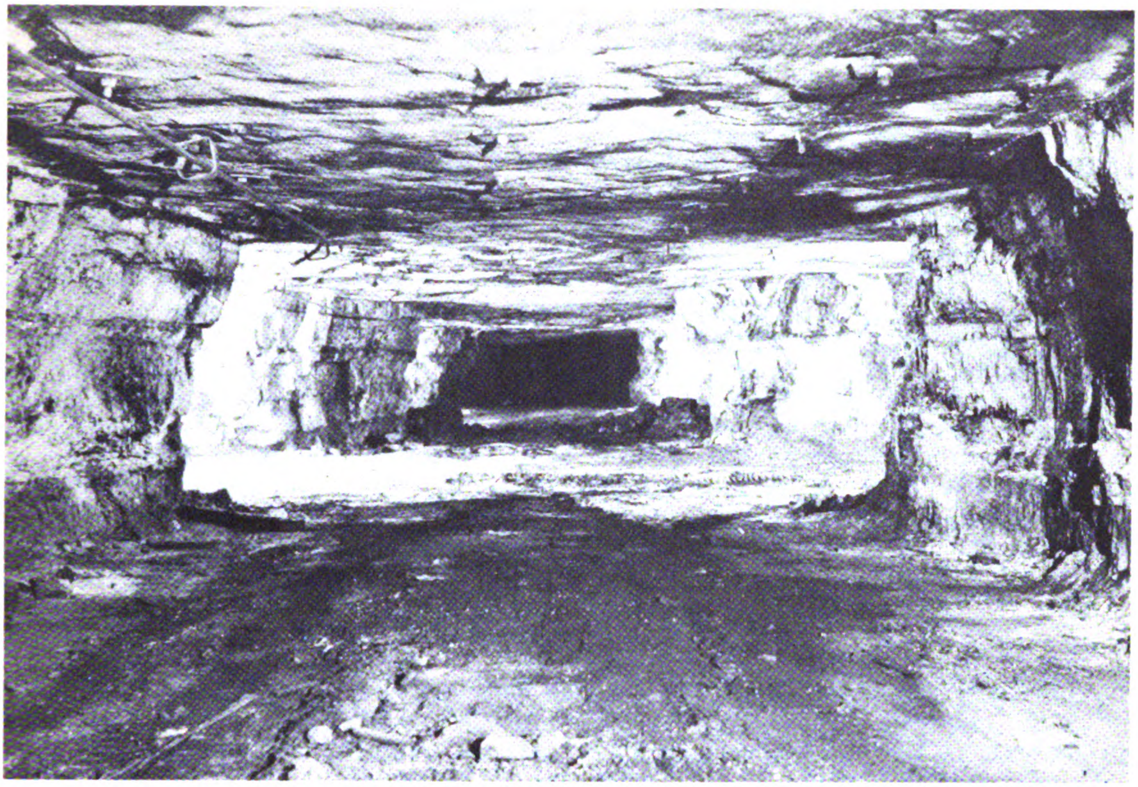


Figure 5. - Advantages and improved roof after bolting (Concord coal mine).

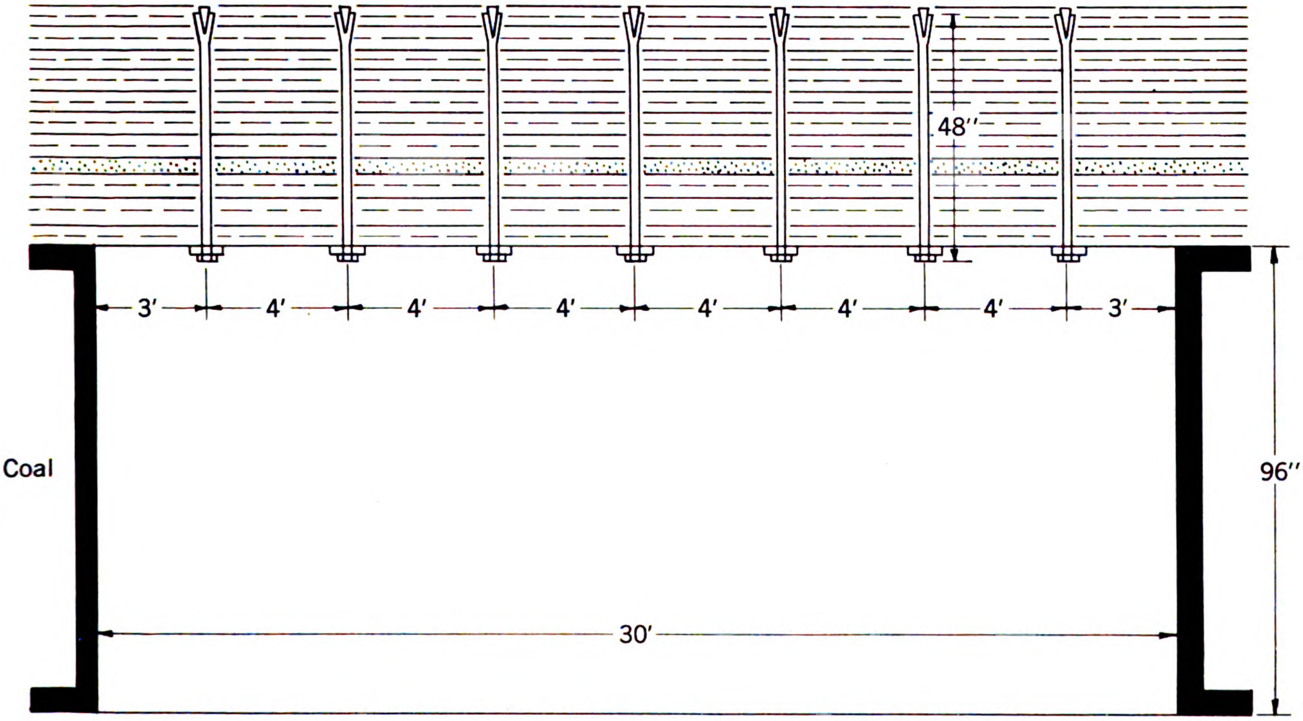


Figure 6. - Rooms driven 30 feet in width and roof bolted (coal mine).

difficulty in trying to support the roof with timbers in the Concord mine, and figure 5 shows clearly the advantages and improved conditions after roof bolting. The two pictures were taken in return aircourses.

After roof bolting had been proved in the Tennessee Co. coal mines and ore mines, it was gradually adopted for various mines throughout the State. As of May 1953, roof bolts have been installed in 33 coal mines, 1 clay mine, and 14 iron-ore mines. Roof bolting has been done in all of the large coal mines, in most of the medium-size coal mines, in several small hand-loading coal mines, and in all iron-ore mines. Of the 14 iron-ore mines, 12 are being operated at present. Nine of the 33 coal mines in which bolts have been used are now closed down, and in 2 mines bolting was discontinued because of improved roof conditions. At the present time 100 percent of the roof is bolted in all the ore mines, the 1 clay mine, and in 6 coal mines. Of the remaining coal mines the coal produced under roof bolts ranges between 4 and 70 percent. In addition to the bolting at the active working faces, bolts have also been used to some extent in virtually every mine to reinforce the roof of haulageways, airways, manways, slopes, pumprooms, underground shops, etc. When roof bolting was begun and for some time thereafter, only 1-inch-diameter, slit-and-wedge-type bolts were used, however, at present a considerable amount of bolting is being done with 3/4-inch-diameter, expansion-type bolts.

## COAL-MINE INSTALLATIONS

The systematic plan of roof bolting adopted for most coal mines required spacing the bolts on a maximum of 4-foot centers. In some mines and in sections of other mines 5- , 6- , and 7-foot maximum spacing, depending upon the roof conditions encountered, was followed. The width of the openings and the distance between bolts determined the number of bolts installed across the openings. Most bolting has been done vertically; however, in some mines at local areas where roof conditions are very poor or faulty, some angle bolting has also been done. Where this latter system was used, the end bolts were installed at an angle of 60° to 70° from the horizontal and over the rib lines, and the in-between bolts were installed vertically. The bolts used throughout the various mines ranged from 30 to 96 inches in length, but most of the bolts ranged from 30 to 72 inches in length. Bolts 84 and 96 inches long were used under special conditions in reinforcing adverse roof or rib conditions at local areas. Of the total number of bolts being used as of May 1, 1953, approximately 88 percent are of 1-inch-diameter slit-and-wedge type and 12 percent are 3/4-inch-diameter expansion type. With few exceptions, an individual steel bearing plate was used on each bolt. Continuous bearing plates of steel or wood were used in selected localities in some mines to reinforce heavy roof at local fault areas and at intersections. The individual steel bearing plates used in the various mines were of varying dimensions, of which the most common sizes were, 6- by 6- by 1/4-inch, 6- by 6- by 5/16-inch, 6- by 6- by 3/8 inch, and 8- by 8- by 3/8 inch. Wooden headers, 2 to 3 inches thick by 8 to 10 inches wide and 20 to 30 inches long were used on bolts between the steel bearing plate and roof in several mines where the immediate roof was weak or fragile.

In addition to the standard bolting plans it was, at times, necessary to supplement the bolts with timbering at local areas to support faulty or heavy roof. The amount and type of timbering done were determined by conditions. In some mines and in sections of other mines systematic roof-control plans have been adopted whereby timbers were used in conjunction with roof bolts as a standard practice.

Some of the various systems of roof control, as followed throughout the Alabama coal mines in which roof bolts were used, are described as follows:

Original from THE OHIO STATE UNIVERSITY

Figure 6 shows a roof-control plan of 1 mines in which slit-and-wedge type bolts, 1 inch in diameter and 48 inches long, were used to support the roof of rooms which were driven 30 feet in width. The main roof strata consisted of strong, firm, sandy shale, which was interstratified with fine sandstone. A firm drawrock averaging about 24 inches in thickness separated the coal seam and main roof in some areas of the mine. The roof was quite free of slips, pots, and rolls. The bolts were installed vertically in sets of 7 across the openings, with an 8- by 8- by 3/8-inch steel bearing plate on each rod. Spacing between bolts, both across the openings and along the openings, was 4 feet. Drilling was done dry with stopers, and dry-dust collectors were used to control the dust. Nuts were tightened with air impact wrenches. Air was furnished by self-propelled mobile compressors. Figure 7 is a bolting plan for haulage entries driven 15 feet in width. The mine roof consists of shale and sandstone interstratified. The strata are irregularly bedded, are of a slippery formation, and contain slip planes and vertical cleats. The coal vein averages 30 inches in thickness, and the roof is brushed to make an overall height of about 72 inches. Wedge-type bolts, 1 inch in diameter and 42 inches in length, were installed vertically in sets of three across the entries with a 6- by 6- by 1/4-inch steel bearing plate on each bolt. The bolts were spaced on 4-foot centers both ways. The holes were drilled and the nuts tightened with stopers. Air was received from portable compressors, and the dust from drilling was controlled with dry dust collectors. Figures 8 and 9 are roof-bolting plans of rooms driven 28 feet wide in a combination clay and coal mine. This mine was operated primarily for the production of fire clay. The coal seam has an average thickness of 28 inches and is underlain with 6 to 10 feet of fire clay; however, only the top 48 inches of clay is mined. The roof is tough stratified shale, which extends about 30 feet upward to a rider seam of coal.

Roof bolting was begun in early 1950, and at that time both coal and clay were being mined and the roof bolted with expansion-type bolts, 3/4 inch by 48 inches, installed vertically on 6-foot centers. See fig. 9.) This method was continued for several months until coal mining was discontinued. Since that time, mining has been confined to the fire clay only, and the coal is held intact by bolts, as shown in figure 8.

The coal was undercut with a mobile mining machine, after which the clay was mined to a depth of 48 inches. The thickness of the coal seam, after undercutting, averages 22 inches. The same type and size bolts, 3/4-inch-diameter expansion type, 48 inches long, previously used to support the firm shale roof are now used to support the coal roof, but instead of the bolts being installed on 6-foot centers they are now spaced on 4-foot centers. A 6- by 6- by 1/4-inch steel bearing plate is used between the roof and nut on each bolt.

Figure 10 shows the roof-control plan followed in a mine that has very weak sandstone roof. Roof bolting in conjunction with timbering is confined to the active working areas in which room entries were driven 25 feet and rooms 30 feet in width. The roof consists of hard, brittle, stratified sandstone, which requires support soon after exposure. The layers range from about 1/2 inch to about 6 inches in thickness, and the adhesive quality between layers is slight.

When roof bolting was first done in March 1950, and for some time thereafter, wedge-type bolts 1 inch in diameter and 72 inches in length were installed vertically on 4-foot centers both ways. The action of the roof strata was such that it was necessary to use posts or timber sets, depending on the conditions, in conjunction with the roof bolts. The roof, whether supported with bolts or timbers or both, tends, at many locations, to take on weight and gradually sag, after which it buckles and breaks between the bolts or timbers. Where these conditions occur the roof becomes quiet after it is broken and the initial pressure is spent, but because of

Original from THE OHIO STATE UNIVERSITY

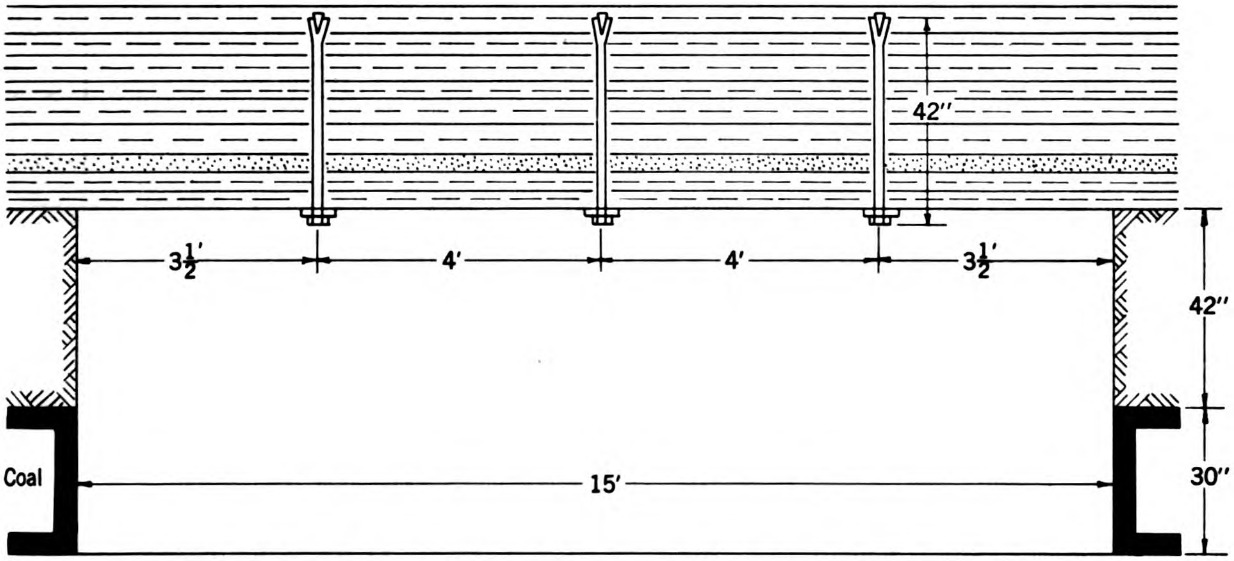


Figure 7. - Entries 15 feet wide, top brushed and roof bolted (coal mine).

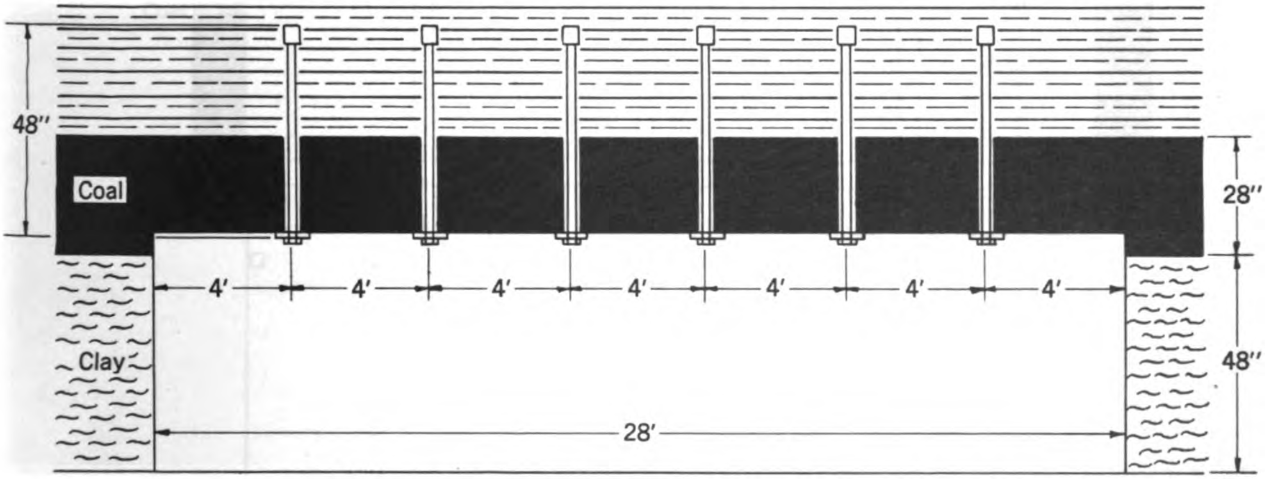


Figure 8. - Coal seam held intact with roof bolts in a combination coal and clay mine.

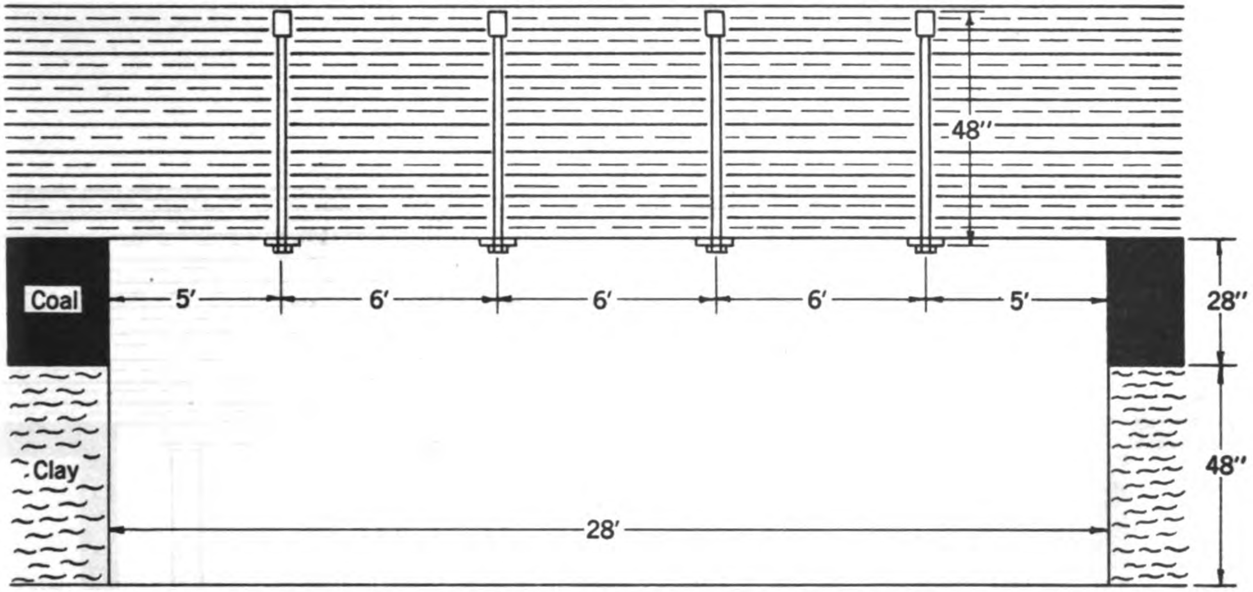


Figure 9. - Rooms 28 feet wide. Roof bolted in a combination coal and clay mine.

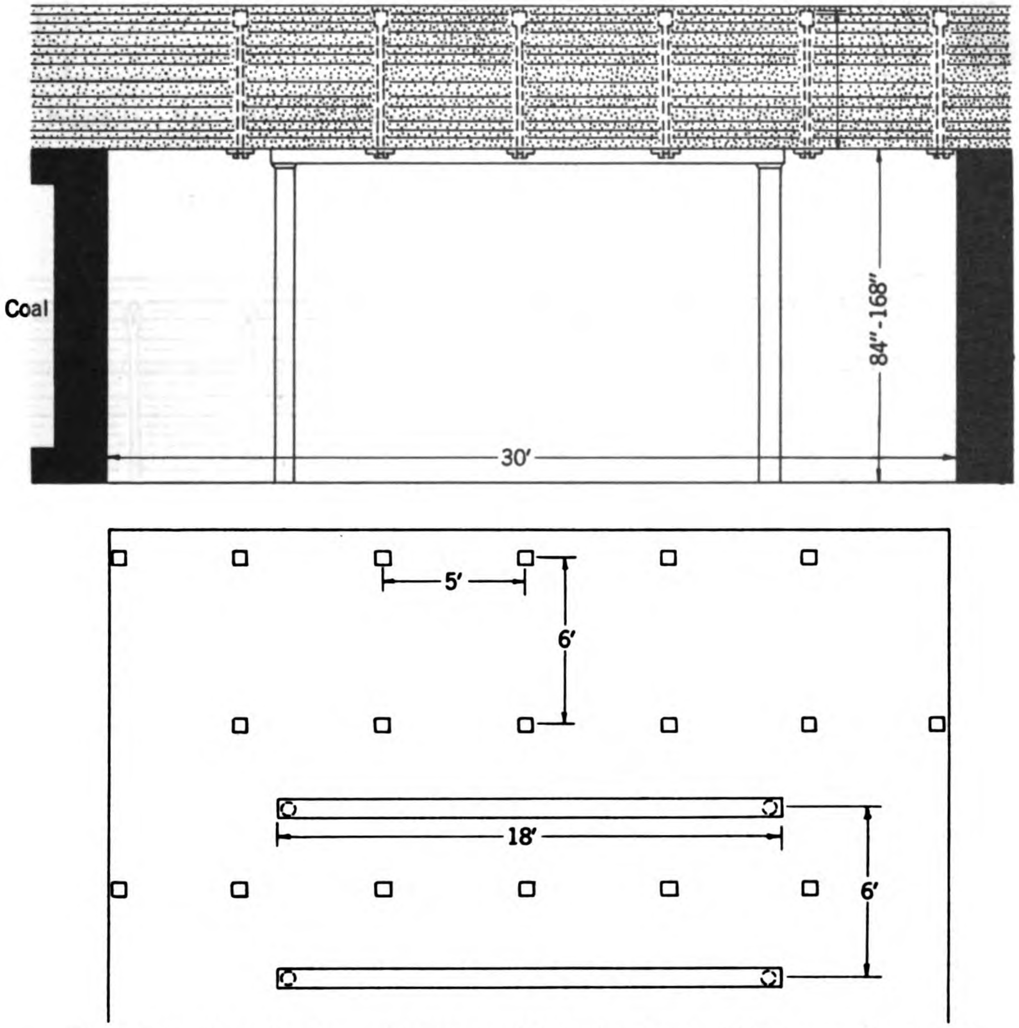


Figure 10. - A combination roof bolting and timbering plan for 30-foot rooms (coal mine).

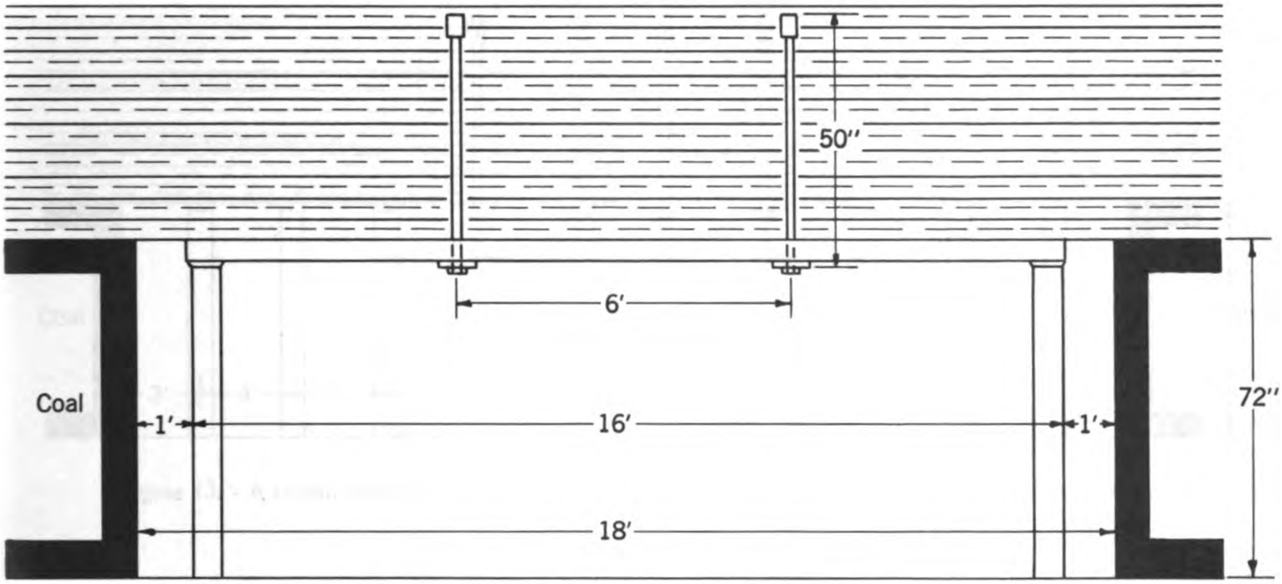


Figure 11. - Roof bolts used in conjunction with three-piece timber sets (coal mine).

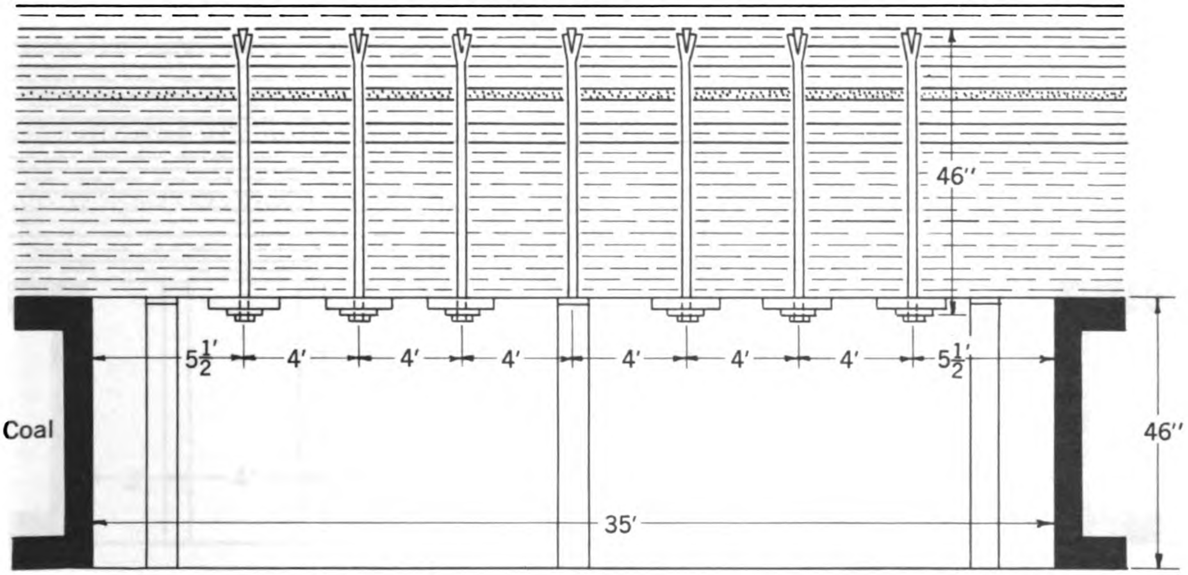


Figure 12. - Posts used in conjunction with roof bolts in 35-foot rooms (coal mine).

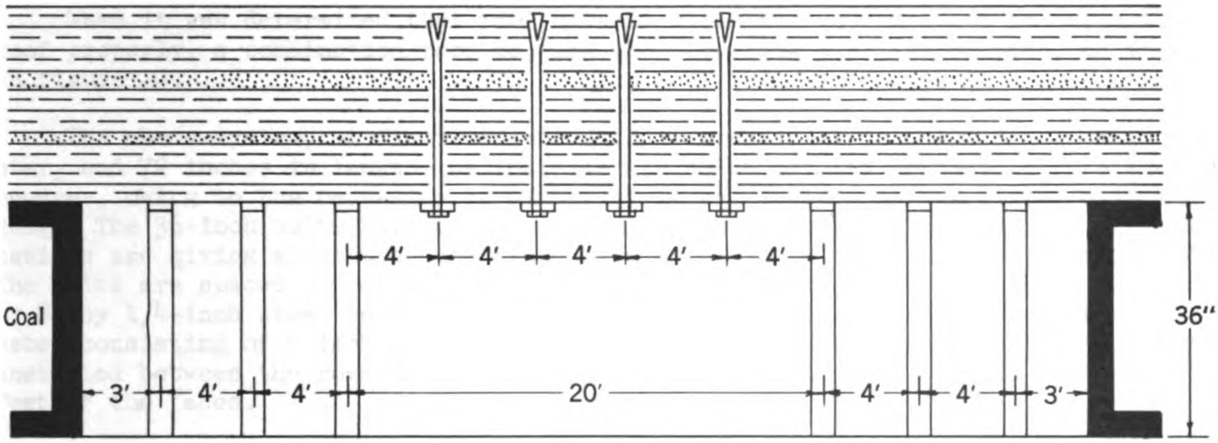


Figure 13. - A combination bolting and timbering plan for rooms driven 42 feet in width (coal mine).

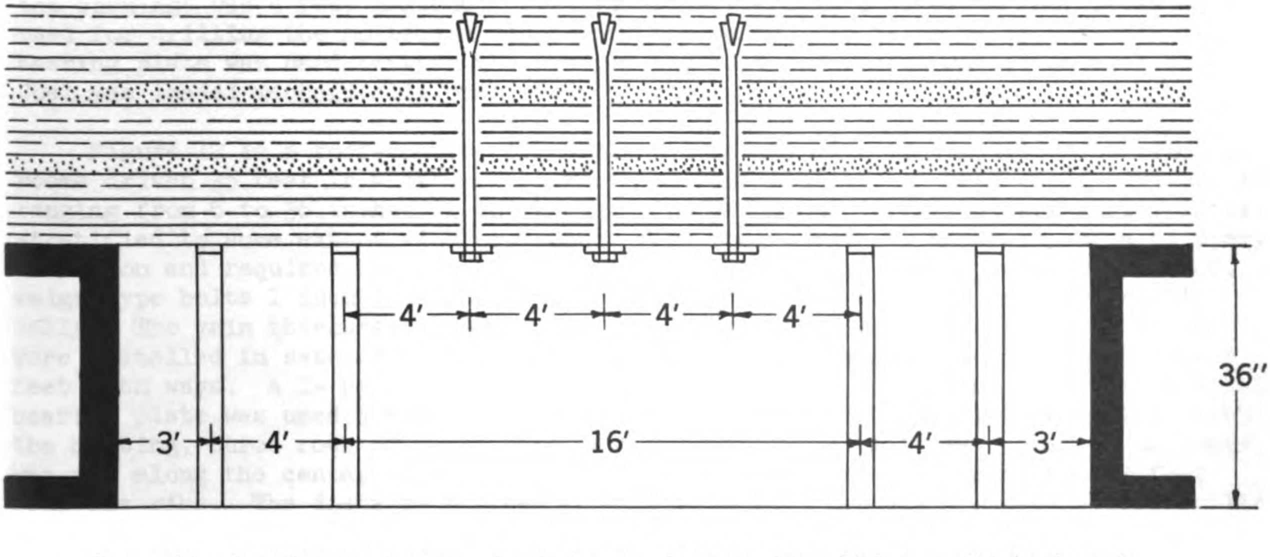


Figure 14. - A combination bolting and timbering plan for rooms driven 30 feet in width (coal mine).

the broken condition of the strata the roof falls progressively to above the ends of the bolts unless it is adequately timbered. Various systems of bolting have been tried, including staggering the bolts and installing the end bolts on an angle over the ribs. Both 1-inch wedge-type and 3/4-inch expansion-type bolts were used, with the same results.

When it was determined that roof bolting alone was not adequate to support the roof properly, a combination roof bolting and timbering plan was adopted, as shown in figure 10.

The above system, at first, required that expansion-type bolts 3/4 inch in diameter, and 72 inches in length, be installed in holes drilled vertically into the roof; however, owing to the necessity of timbering it was decided to try bolts 36 inches long. The 36-inch bolts have been used entirely since early 1952 and from all indications are giving about the same protection as was obtained with the 72-inch bolts. The bolts are spaced 5 feet apart across and 6 feet apart along the openings. A 6- by 8- by 1/4-inch steel bearing plate was used on each bolt. Three-piece timber sets, consisting of 6 inch by 8-inch by 18-foot headers supported with posts, were installed between the rows of bolts on 6-foot centers and were kept to within 15 feet of the faces.

A roof-control plan in which bolts are used in conjunction with three-piece timber sets is shown in figure 11. The roof in the mine where this system is followed is very weak sandy shale. Slips, angular joints, and some pots are prevalent throughout the strata. Entries, rooms, and crosscuts were all driven about 18 feet in width. Coal was loaded mechanically onto chain conveyors. Each installation utilized either a 2- by 8-inch by 16-foot or a 4- by 8-inch by 16 foot wooden collar, (depending upon roof conditions), 2 posts, and 2 bolts. In making the installations the collars were first supported against the roof with 2 screw jacks, after which 2 bolt holes were drilled through each collar and into the roof to accommodate 3/4- by 50-inch expansion-type bolts. The bolts were spaced 6 feet apart and are 3 feet on each side of the center line. After the bolts were installed, a wood post was set under each end of the collars. The distance between sets along the openings was 4 feet maximum. Electric-rotary drills mounted on roof jacks were used for drilling the holes and tightening the bolts. An 8- by 8- by 3/8-inch steel bearing plate was used between the head of the bolt and wooden collar on each bolt. Coal was loaded mechanically onto chain conveyors.

Figure 12 is a roof-control plan followed in one mine in supporting the roof of rooms driven 35 feet in width. The immediate roof consists of weak shale (draw rock) ranging from 6 to 36 inches in thickness. The main roof is fairly hard shale, interstratified to some extent with sandstone. The roof strata is generally of a slippery formation and requires support immediately after exposure. In supporting the roof, wedge-type bolts 1 inch in diameter and 46 inches in length were installed vertically. The vein thickness of 46 inches precludes use of longer bolts. The bolts were installed in sets of 7 across the openings and the spacing between bolts was 4 feet both ways. A 2- by 2- by 20-inch wooden header and a 6- by 6- by 1/4-inch steel bearing plate was used between the nut and header on each bolt. In conjunction with the bolting, three rows of posts were kept near the working faces. One row of posts was set along the center line and 1 row along each side of the rooms about 3 feet from the ribs. The distance between the posts in each row was 4 feet. Stoper drills were used to bore the holes and tighten the nuts. Water was used to control the dust during drilling. Coal was loaded mechanically onto shaker conveyors.

A combination of timbering and bolting plans as used in one mine to support the roof of 42- and 30-foot-wide rooms are shown in figures 13 and 14. The coal vein averages 36 inches in thickness. The roof consists of hard shale interbedded to some

Original from THE OHIO STATE UNIVERSITY

extent with sandstone. The strata vary from weak to strong and are embedded to various degrees with coal streaks, slips, pots, and horsebacks. Figure 14 shows the roof-control plan adopted for 30-foot rooms, and figure 13 is the plan for 42-foot rooms. In the 30-foot rooms a combination of 4 posts and 3 bolts was used to the set across the openings, and in the 42-foot rooms a combination of 6 posts and 4 bolts was used. All supports across the rooms were spaced on 4-foot centers, as shown in the sketches, and the distance between supports along the rooms was also 4 feet. Wedge-type bolts, 1 inch in diameter and 30 inches in length, were installed vertically with an 8- by 8- by 3/8-inch steel bearing plate on each bolt. Stopers were used in drilling the boreholes and anchoring the bolts, and dry dust collectors were used to control the dust. Coal was loaded mechanically onto shaker conveyors.

Figure 15 is a plan showing rib and roof bolting being done in one mine along an old haulage slope. The slope was developed many years ago, and since then many timbered roof failures have occurred along sections of the slope at various locations. The roof strata consist of fairly hard, bedded, sandy shale of various thicknesses and contain some angular joints and slips. The roof strata at places gradually become weak and begin to sag and break, overloading and breaking the timbers. Some roof failures consisted of a series of falls which occurred over the years and in many instances extended for a total distance of about 28 feet above the bottom. Timbering crews were used constantly along the slope for retimbering and scaling dangerous loose roof and ribs. Various types of timbering have been used, depending upon the height and roof conditions encountered. The maximum width of the slope is about 25 feet.

Rib and roof bolting of the slope was begun in 1949 and is still in progress. Most of the bolting has been done in ribs and roof at places where falls had occurred in the past. Other bolting is done in original roof that is still intact. At locations where failures had occurred in the past, the timbering was removed and the ribs and roof scaled to the solid before bolts were installed. Wedge-type bolts, 1 inch in diameter and 60 and 96 inches in length were used. The 60-inch bolts were used to support the roof and the 96-inch bolts to support the ribs. The roof bolts were installed vertically, and the rib bolts were installed at various angles between horizontal and vertical, depending upon the arching of the ribs. The amount of roof exposed between the arching of the ribs ranged between 5 and 15 feet. The standard for bolt centers is 4 feet maximum; however, many bolts were less than 4 feet apart. Steel plates 6- by 6- by 1/2 inch, 8- by 8- by 3/8-inch, and 5- by 8- by 1-inch were used as bearing plates.

Until May 1953 approximately 14,000 bolts had been used in reinforcing the ribs and roof along the slope for about 4,400 linear feet. Since the job was begun there were no failures of bolted roof and no sloughing of roof or rib material from between the bolts.

Pillar extraction in which roof bolts were used in conjunction with conventional timbering was being practiced in four coal mines. The open-end method of recovery was followed, in which cuts or lifts were mined from 1 or 2 gob sides of a pillar, and fenders or stumps of coal were not left adjacent to the gob as the lifts were advanced. Virtually the same system, with slight variations, was followed in the four mines. In pillaring, a double row of breaker posts was kept set to within 6, 8, or 10 feet (determined by the equipment used and roof conditions encountered) of the working faces before undercutting, and extending diagonally across the openings. Bolts, 4 feet apart in a single row, were installed a maximum of 2 feet from the faces after each lift of coal was loaded out. Slit-and-wedge-type bolts, 1 inch in diameter, nominal (0.906) inch, with rolled threads, 36 or 48 inches in length (depending upon the mine or roof conditions) were anchored with 7/8-inch-thick

Original from THE OHIO STATE UNIVERSITY

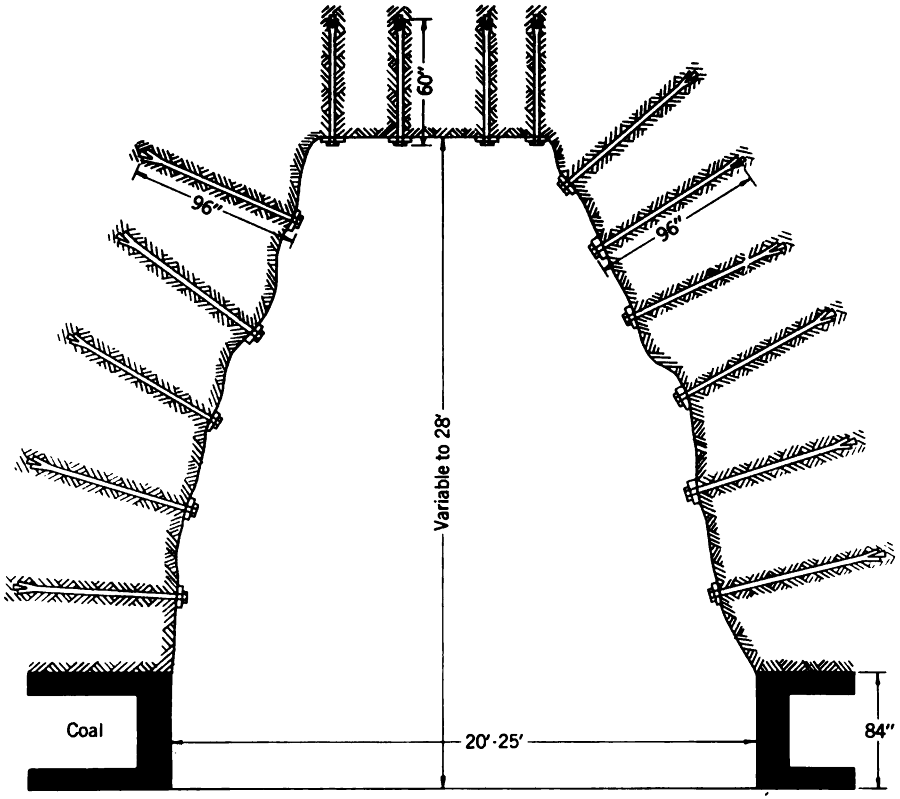
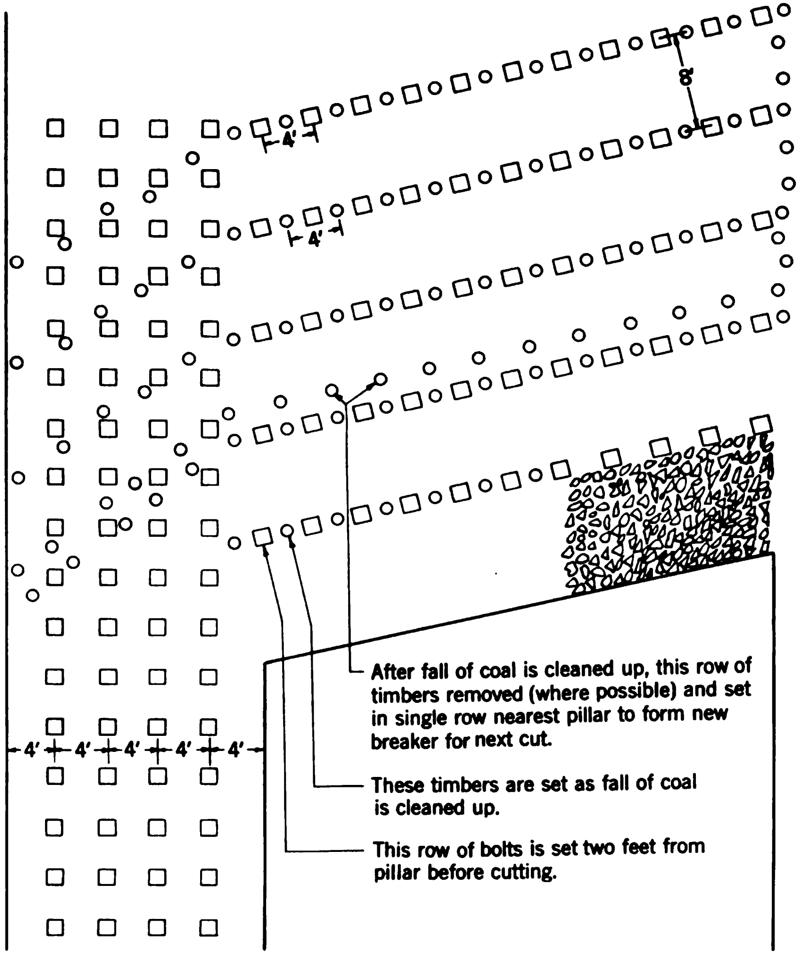


Figure 15. - Roof and rib bolting along an old haulage slope (coal mine).



After fall of coal is cleaned up, this row of timbers removed (where possible) and set in single row nearest pillar to form new breaker for next cut.

These timbers are set as fall of coal is cleaned up.

This row of bolts is set two feet from pillar before cutting.

Figure 16. - Roof bolts used in conjunction with timbering in pillar extraction (coal mine).

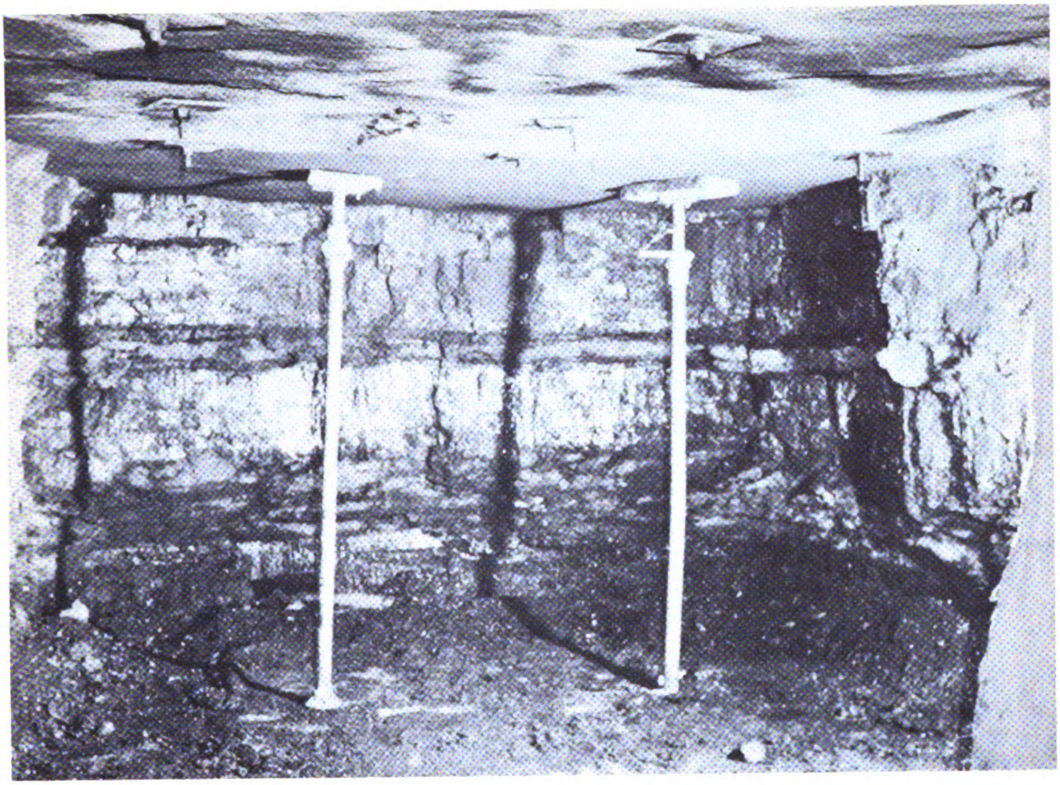


Figure 17. - A place ready to be bolted with safety timbers in place.

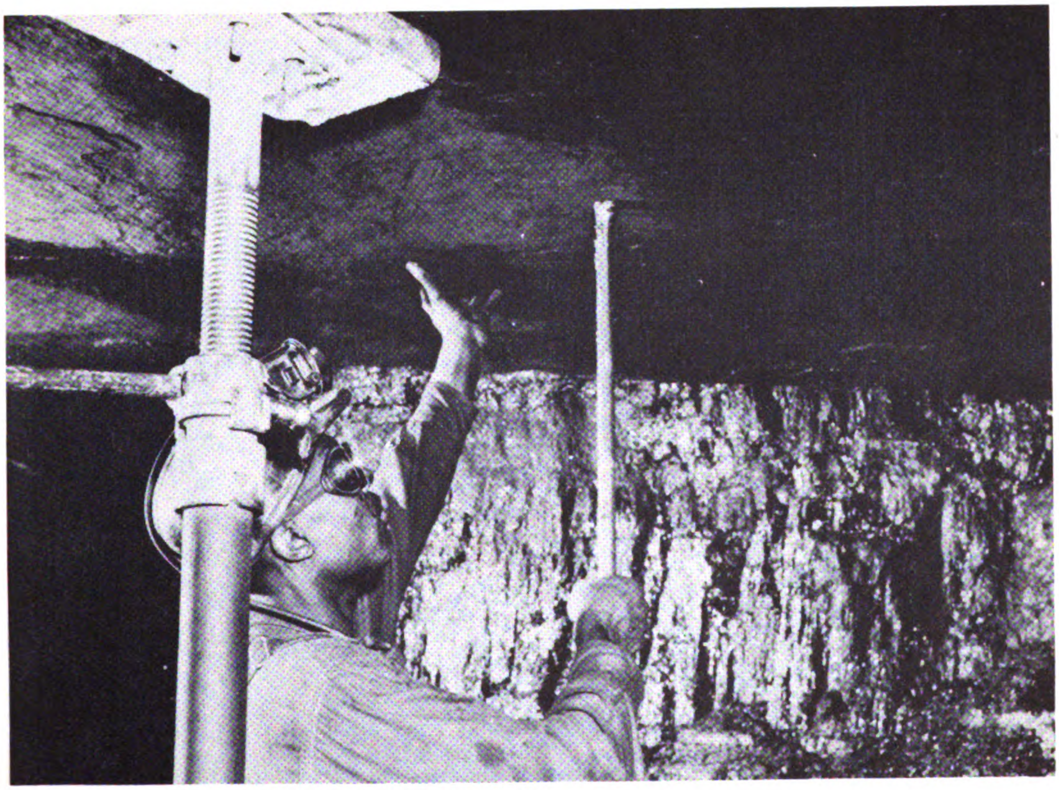


Figure 18. - Roof is thoroughly tested before beginning to bolt.

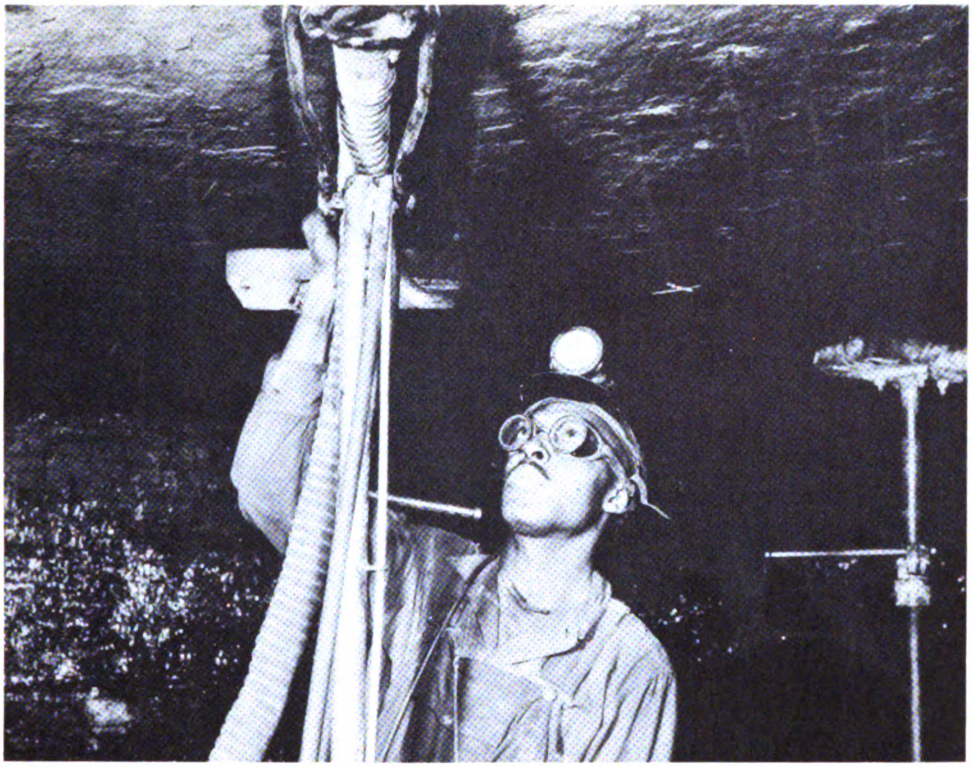


Figure 19. - Permissible dust collector is placed where hole is to be drilled.

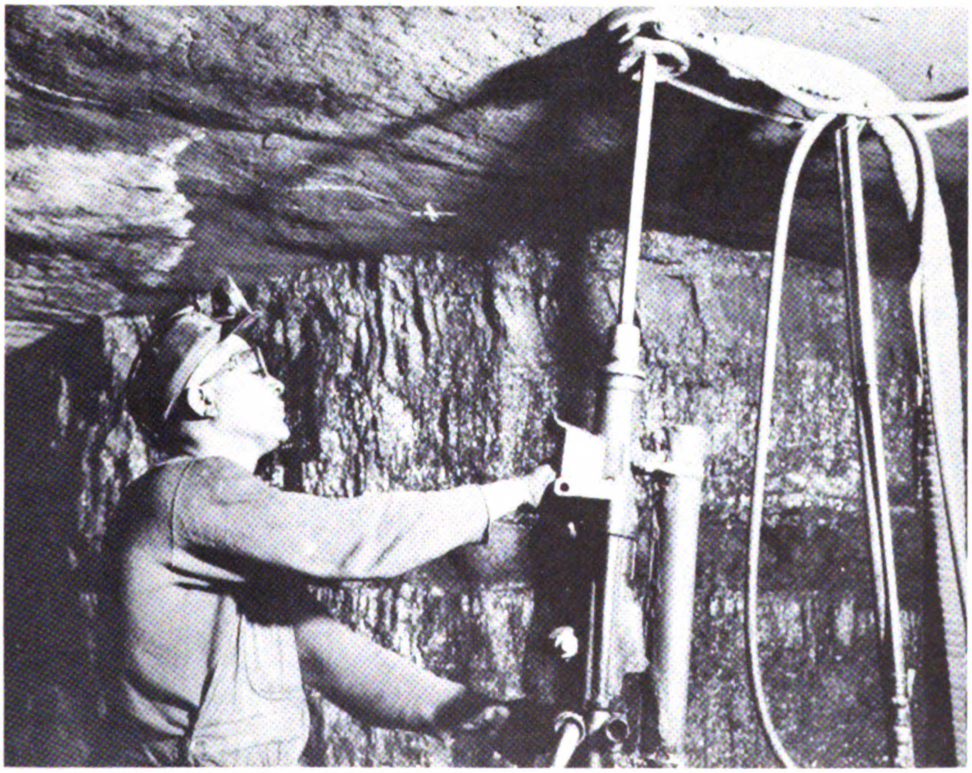


Figure 20. - Roof bolter maintains firm grasp on stoper as hole is drilled.

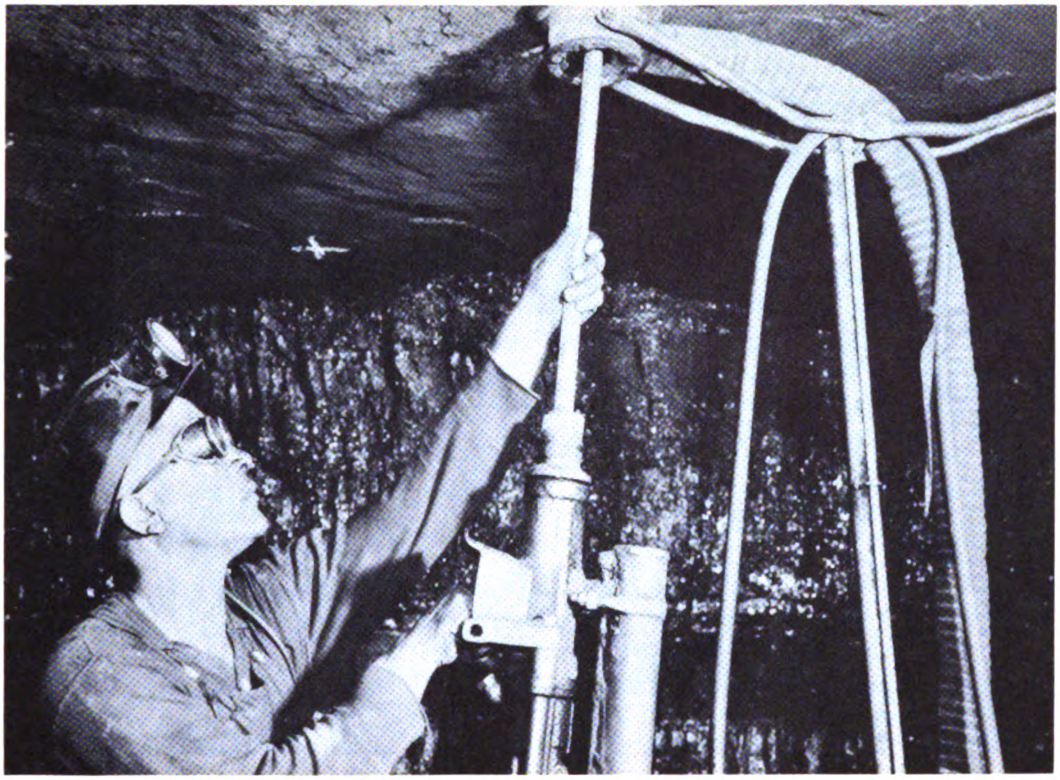


Figure 21. - Roof bolter holds onto drill steel as it is withdrawn.

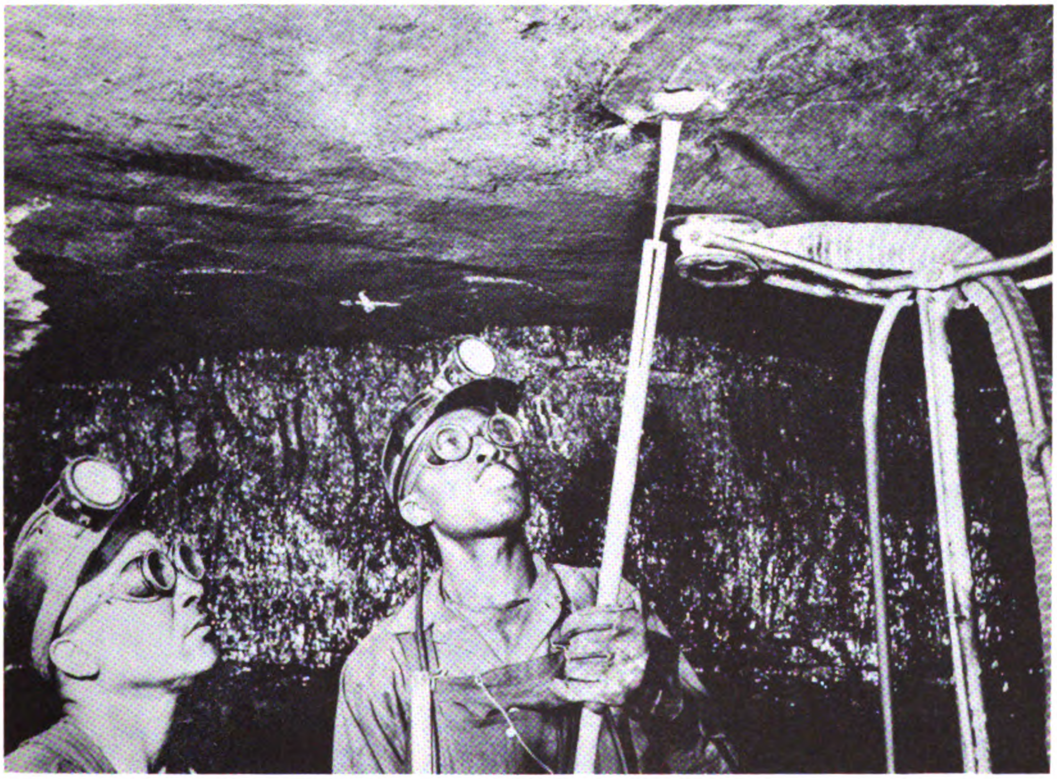


Figure 22. - As hole is completed, roof bolt is inserted.

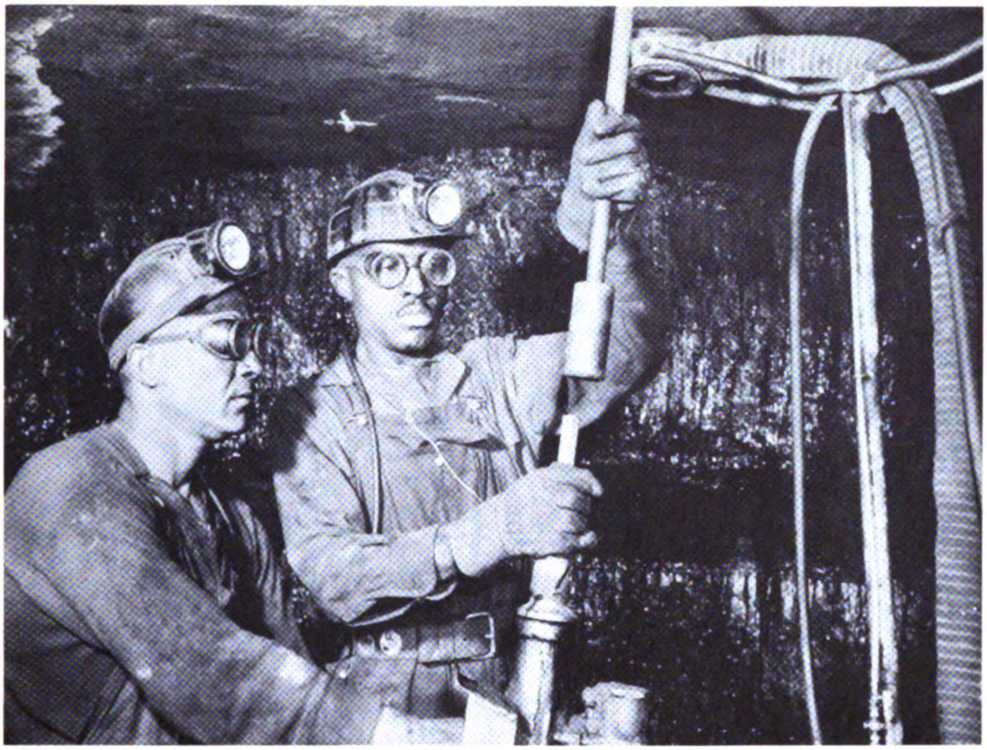


Figure 23. - Roof bolt is driven onto wedge with stoper for 10 seconds.

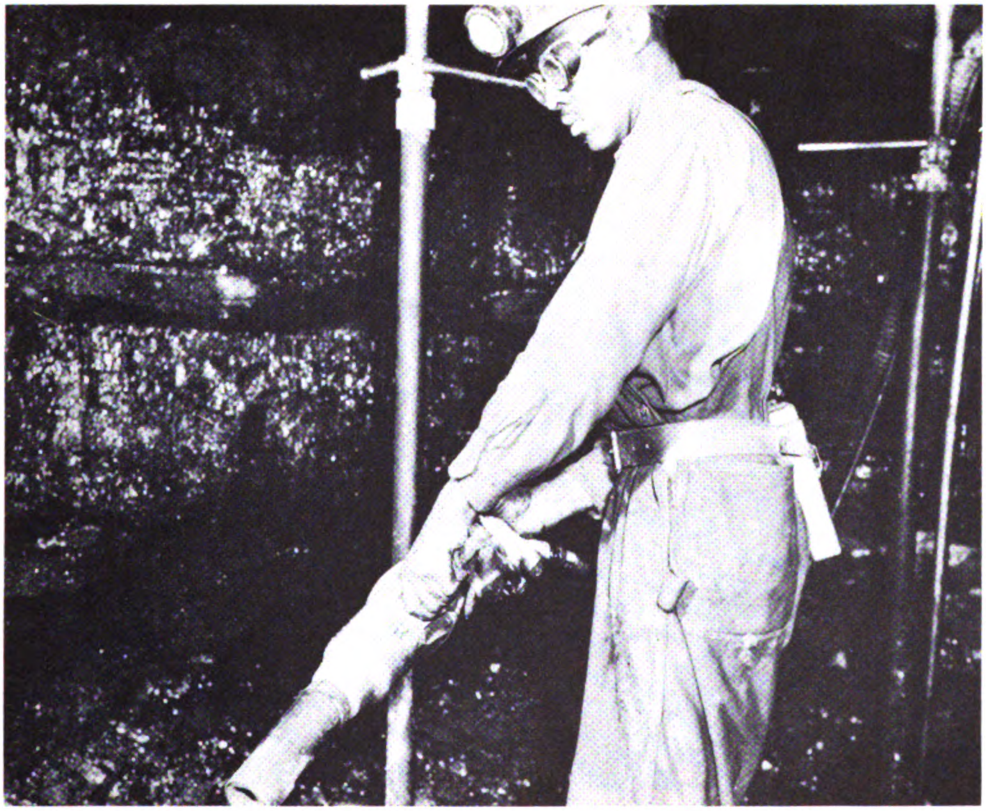


Figure 24. - Impact wrench is tested for correct rotation.

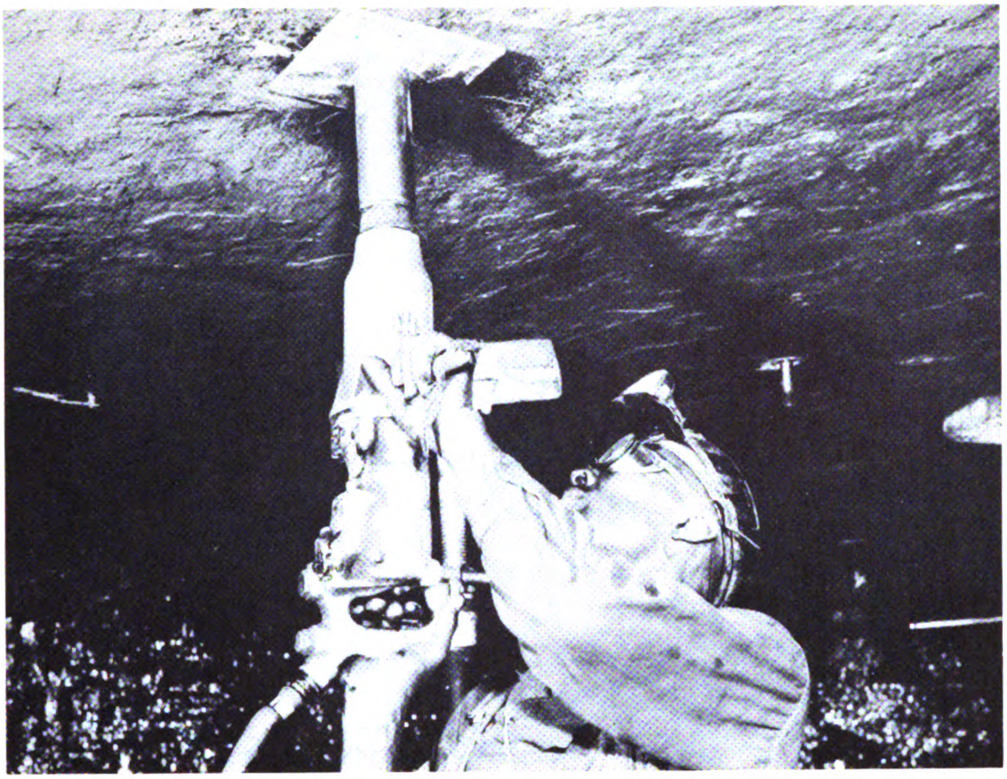


Figure 25. - Nuts are tightened on bolt until bearing plate begins to cup.

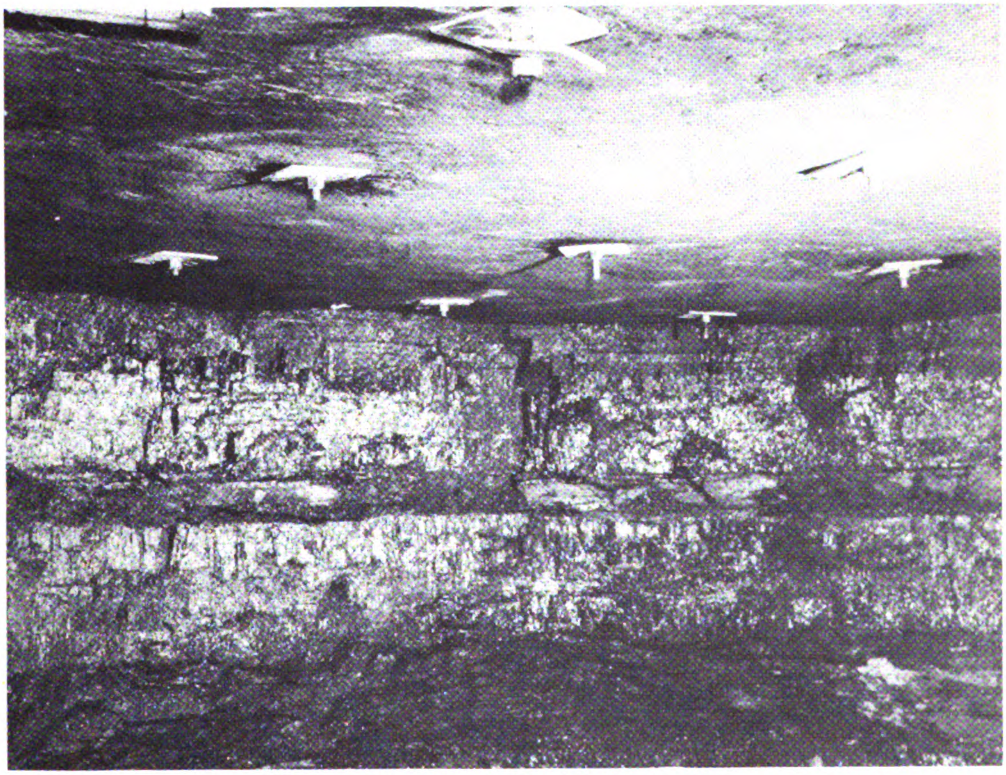


Figure 26. - A place after it has been bolted.

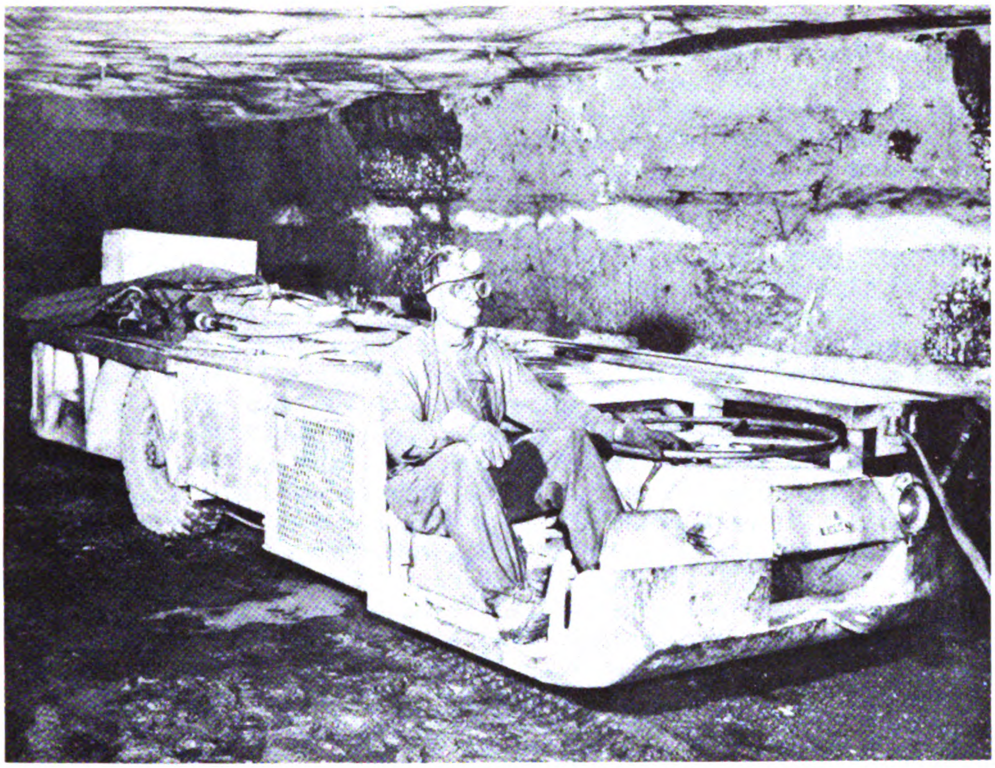


Figure 27. - Mobile air compressors with all necessary tools and supplies.

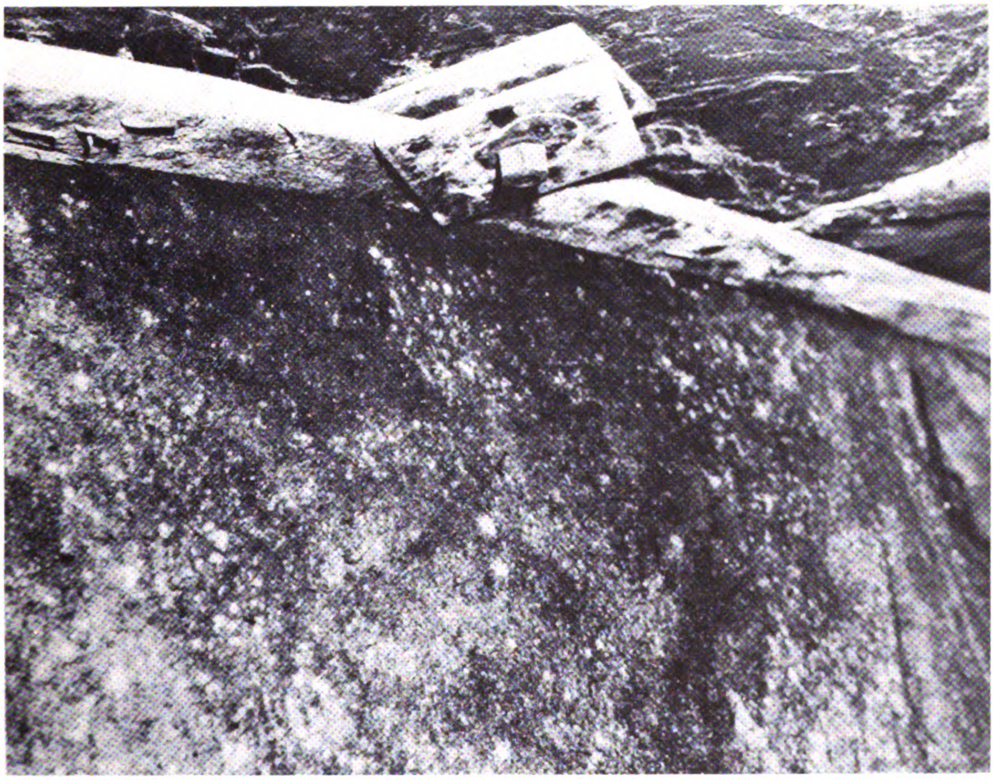


Figure 28. - Roof bolts are also used in hanging the ventilation curtains.

wedges in 1-3/8-inch-diameter holes drilled vertically into the roof. An 8-inch-square by 3/8-inch-thick steel bearing plate was used on each bolt. Holes were drilled dry with pneumatic percussion stopers, and the dust was controlled with dust collectors. Air impact wrenches were used in tightening the nuts. In all four mines coal was loaded mechanically into shuttle cars. A typical plan is shown in figure 16.

Percussion stoper drills were used in 17 mines, and rotary drills were used in 5 mines in boring the bolt holes. Of the 17 mines using stopers, 16 were using 1-inch-diameter slit-and-wedge-type bolts, and 1 mine was using 3/4-inch-diameter expansion-type bolts. Of the 17 mines doing percussion drilling, 7 were using water, and 8 were using dry dust collectors to control the dust during drilling. In the other two mines the roof was bolted only occasionally, and the dust was not controlled. In all 5 mines doing rotary drilling, 3/4-inch-diameter, expansion-type bolts were used; in 1 of the mines the dust from drilling was controlled with water; and in 4 of the mines drilling was done dry, and the dust was not controlled. Self-propelled air compressors, with all necessary tools and supplies, were used by the bolting crews of 4 of the 17 mines doing percussion drilling, and stationary or portable air compressors were used in the remainder. All 3/4-inch-diameter expansion-type bolts were anchored in 1-3/8-inch-diameter holes. In mines using 1-inch-diameter, slit-and-wedge-type bolts, the installations were made by anchoring the bolts in 1-1/4- , 1-5/16- and 1-3/8-inch-diameter holes with 3/4- or 7/8-inch-thick wedges. The hardness of the roof rock at anchorage, the type of bolt used, and whether the slot was burnt, sheared, or punched out determined the diameter of the holes and the thickness of the wedges. Rotary drilling was done with two-prong tungsten carbide-insert tip bits. Of the 17 mines doing percussion drilling, 15 used 4-point throw-a-way bits, 1 used 4-point tungsten carbide-insert tip bits, and 1 used chisel-point tungsten carbide-insert tip bits. Where rotary drilling was practiced, the 3/4-inch bolts were also tightened with the drills, and in mines where percussion drilling was practiced the bolts were tightened in 12 mines with air-impact wrenches, in 3 mines with stopers, and in 2 mines by hand. Companies operating 14 of the mines have available torquometers and pull testing equipment for making periodic checks to determine the effectiveness of the roof bolt installations.

A complete cycle of operation followed in several coal mines operated by the Tennessee Co. in installing a bolt is shown in figures 17 through 25, inclusive. First the place is made ready by setting safety jacks between the last row of bolts and the face. (Fig. 17.) The roof is then tested (fig. 18), and a permissible dust collector is placed in position before drilling is begun (fig. 19). When drilling is completed (figs. 20 and 21), the slit-and-wedge-type bolt is inserted into the hole (fig. 22) and driven onto the wedge with a stoper for at least 10 seconds (fig. 23). The impact wrench is then tested for correct rotation (fig. 24) and the nut tightened on the bolt until the bearing plate begins to cup (fig. 25). A working place after it has been bolted is shown in figure 26. In making the above installations, mobile air compressors with all necessary tools and supplies are used by the roof-bolting crews. (Fig. 27). In addition to the bolts being used to reinforce the roof, they are also so used in the face areas for hanging the ventilation curtains, as shown in figure 28.

## ORE-MINE INSTALLATIONS

The system of roof bolting adopted for the ore mines varies with roof conditions encountered. The spacing between bolts across the openings and along the openings ranged from 4 to 8 feet, the majority of bolting being done on a maximum of 5-foot spacing. The number of bolts that were used across the openings was

Original from THE OHIO STATE UNIVERSITY

determined by the spacing and the width of places. All mines, except one, used the 1-inch-diameter slit-and-wedge-type bolt, and the one mine used a 3/4-inch-diameter expansion-type. Bolts varied in lengths ranging from 36 inches to 120; the lengths most commonly used were between and including 36 and 72 inches. Bolts 96 and 120 inches long were only used under special conditions in reinforcing heavy and faulty roof. In some mines all bolting was done vertically, using an individual steel bearing plate on each bolt. In other mines a combination of vertical bolting and angle bolting was followed. The combination system required that bolts used near the rib lines be installed at an angle of about 60° or 65° from the horizontal over the ribs and that the intermediate bolts be installed vertically. This system was generally used where roof conditions were poor or the roof showed signs of taking weight. In workings that have a short life, such as rooms, the bolts were installed with individual steel bearing plates, and in entries that have a long life a continuous steel bearing plate of 5-inch steel channel, 20 feet in length, was utilized with each set of bolts. Where the above plan was followed, entries and rooms were usually driven 20 to 32 feet in width, and a set of 5 bolts was used across the openings. A typical installation plan of this system with a continuous steel bearing plate of 5-inch steel channel and 1-inch-diameter slit-and-wedge-type bolts 72 inches in length is shown in figure 29. The same plan was followed, whether continuous or individual bearing plates were used. Figure 30 shows the bolting plan as followed in one mine in supporting the roof of places driven 25 feet in width in which slit-and-wedge-type bolts, 1 inch in diameter and 50 inches in length were installed vertically in sets of 5 across the openings. The spacing between bolts was 4 feet both ways. The above installations are typical of most of the bolting done in the ore mines. Men drilling the face under bolted roof are shown in figure 31, and men loading ore under bolted roof are shown in figure 32. Figure 33 shows the old method of roof support in which steel collars were used and the new method in which 5-inch steel channel and bolts were used. A special installation to support weak roof at a wide intersection (about 45 feet) is pictured in figure 34. In this type installation 5-inch steel channels were used across the openings with 8- or 10-foot bolts.

Percussion drilling with stopers, in which water was used to control the dust, was followed in all ore mines in boring the bolt holes. Air impact wrenches were used to tighten nuts. Stationary compressors on the surface of various mines furnished air for stoper and impact wrench operation and also for the face-drilling equipment. In all mines bolt holes were drilled with tungsten carbide-insert bits. The type and size of bits used were 1-3/8-inch chisel point in 2 mines, 1-3/8-inch 4 point in 1 mine, and 1-1/4-inch chisel point in 7 mines. Conventional stopers with various length air legs were used to bore the holes in all of the ore mines. Stoper drilling in most instances was done from the bottom or footwall; however, at high places in some mines drilling was done from wooden platforms or scaffolds, and in other mines the installations were made from atop self-propelled machines with variable height platforms, as shown in figure 35.

In ore mines being robbed, the slabbing method of recovery is generally followed. By this system openings were driven in widths ranging from 20 to 25 feet and roof bolted during first mining, after which a single 6- to 7-foot slab was robbed from each side of the pillars left standing. In some mines the slabbed areas were roof bolted on 4- or 5-foot centers while loading was in progress, and in other mines the slabbed areas were not roof bolted. In one small operation in which pillars were being extracted only at local areas, the full retreat system was followed in recovering the available pillars in old workings. In retreating, all available ore, except some small stumps that were not safe to mine, was recovered. The roof in this mine is strong and generally self-supporting. Slit-and-wedge-type bolts, 1 inch in diameter and 60 inches in length, were only used where deemed necessary. Where the bolts were used they were installed vertically on about 5-foot centers.

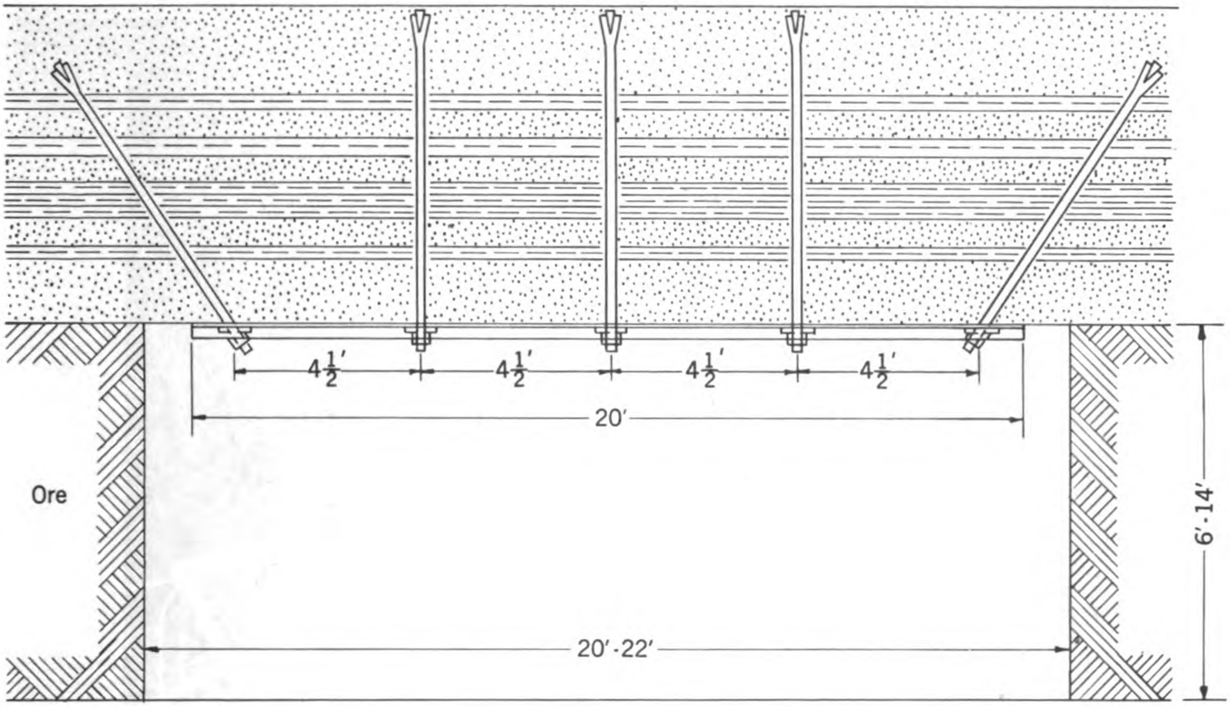


Figure 29. - A combination of vertical and angle bolting in the ore mines.

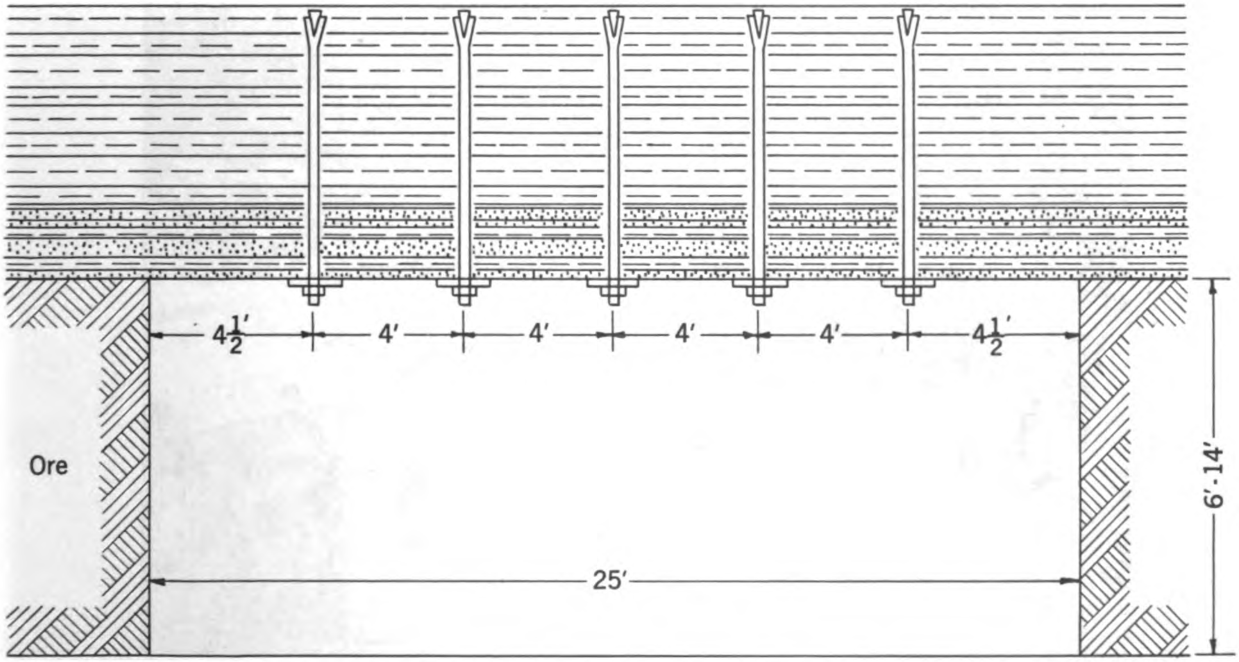


Figure 30. - Vertical bolting in the ore mines.

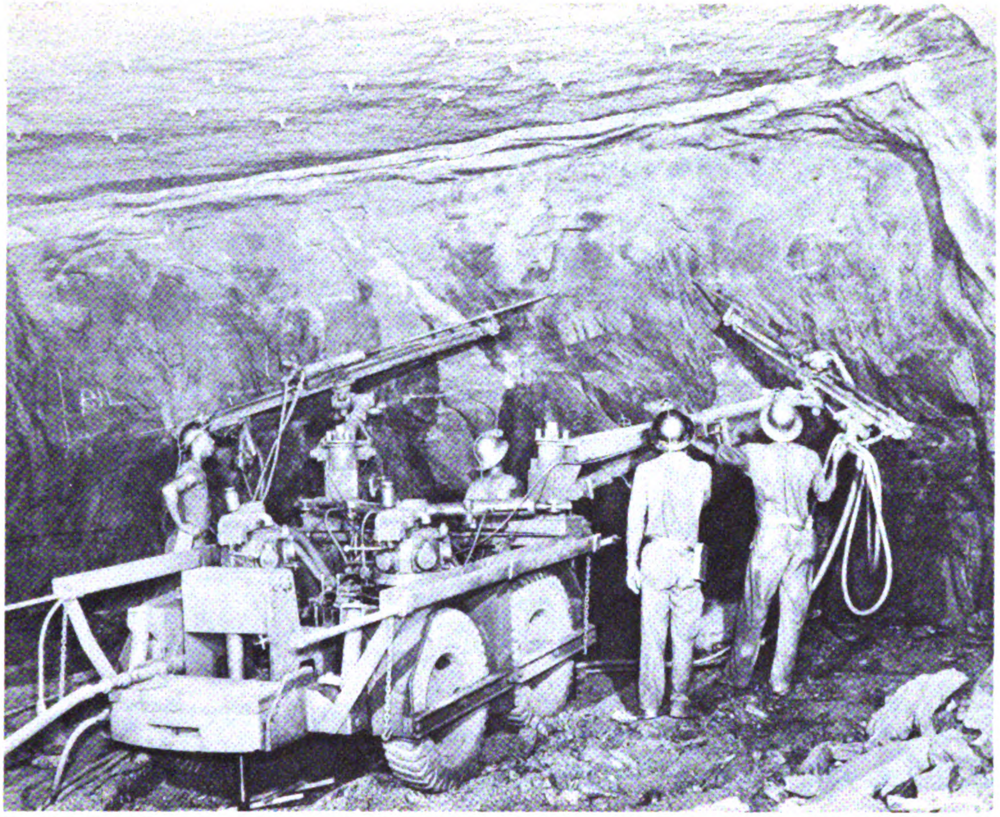


Figure 31. - Drilling the face under bolted roof in an ore mine.

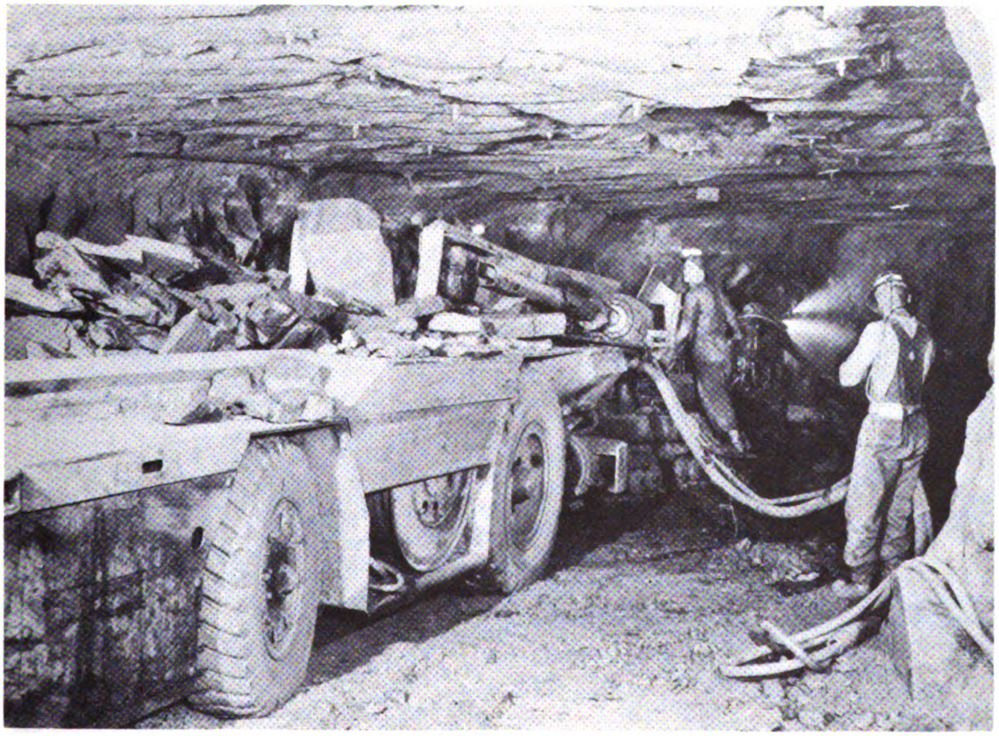


Figure 32. - Loading ore under bolted roof.

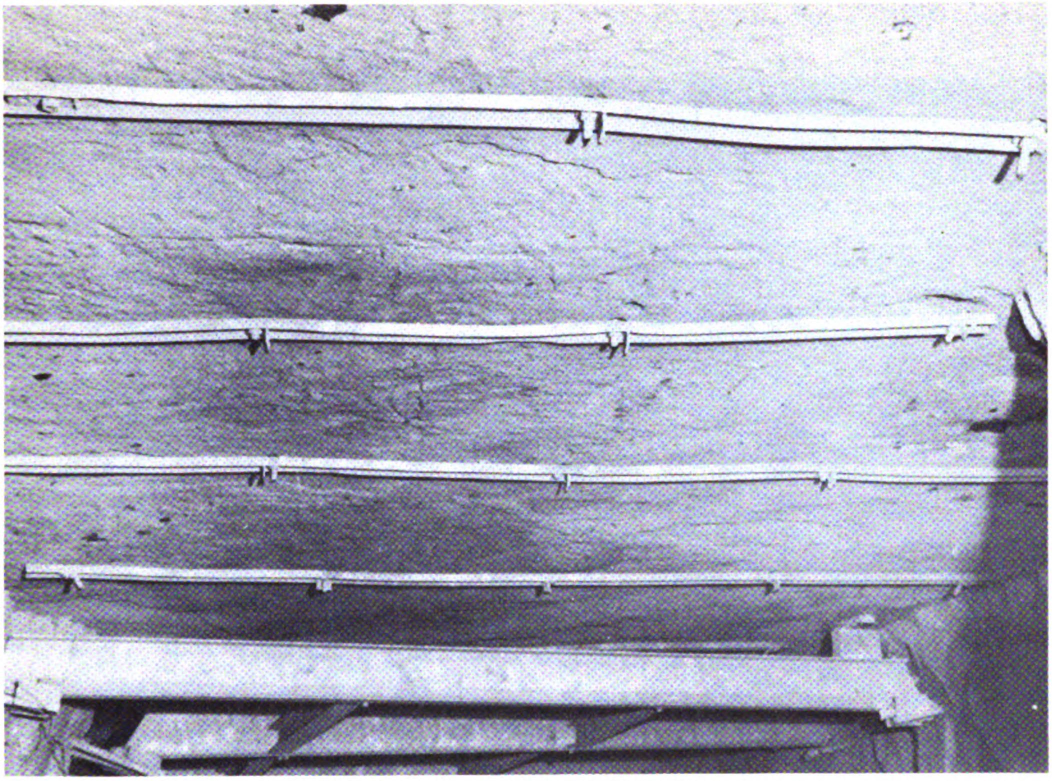


Figure 33. - The old and new methods of roof support in an ore mine.

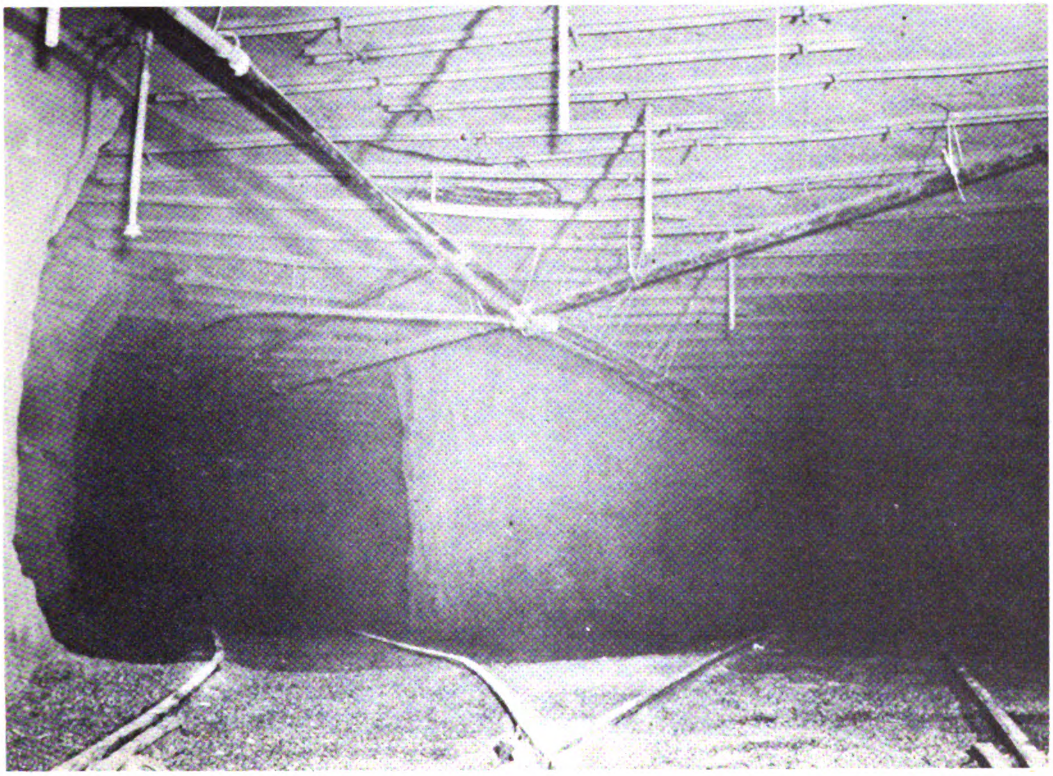


Figure 34. - Heavy roof at a wide intersection supported with bolts (ore mine).

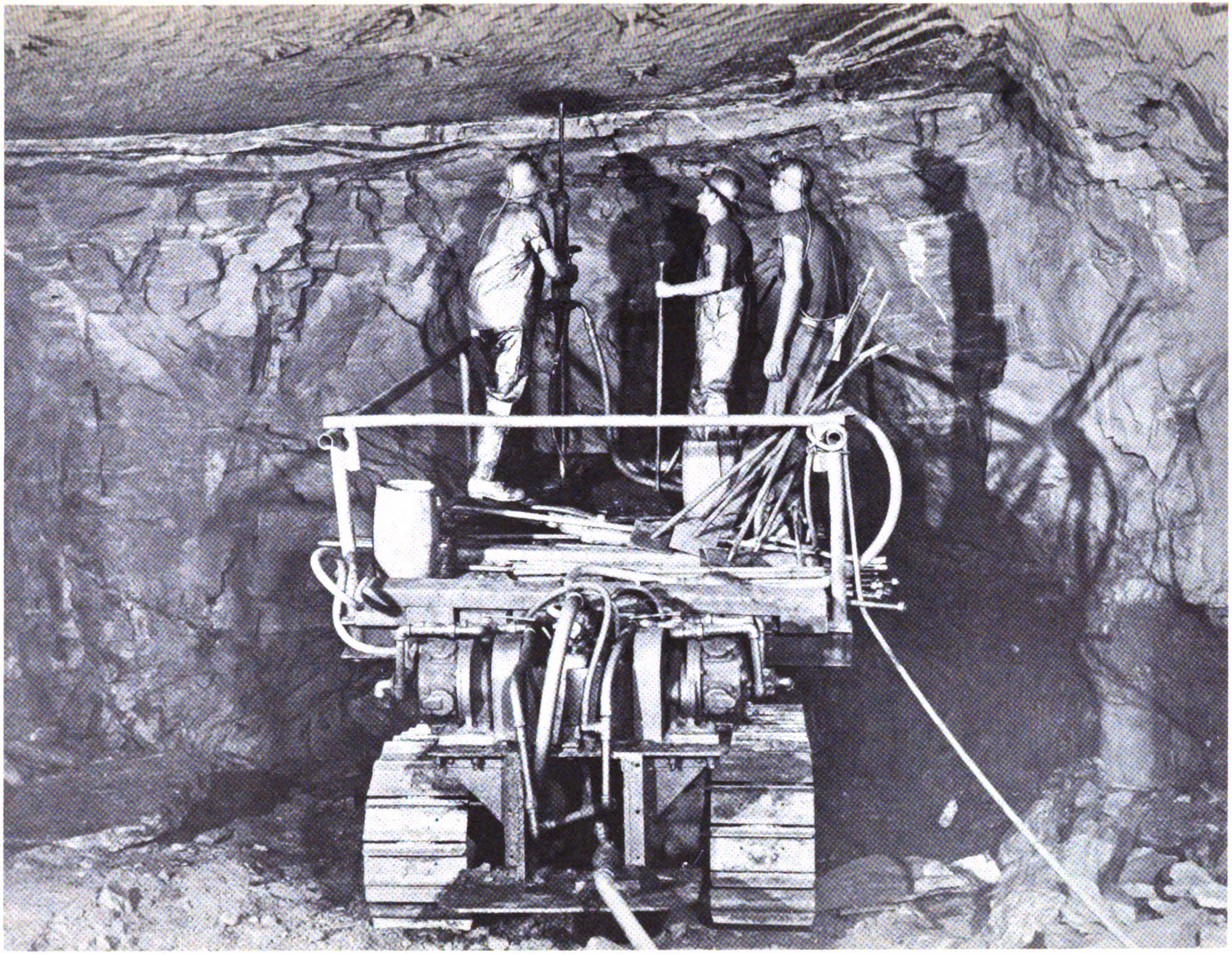


Figure 35. - A working place being roof bolted in an ore mine.

## FAILURES OF BOLTED ROOF

Since roof bolting was begun there have been failures of bolted roof in most of the coal and iron-ore mines in which roof bolts have been used. In mines free of failures, bolting has been done on a small scale or was confined to narrow entries. The number of failures in each mine varied with roof conditions and the amount of bolting done. Most failures were in the larger operations where roof conditions were poor or faulty. In some mines having fairly strong roof where a considerable amount of roof bolting had been done for over 3 years, there had been only 1, 2, or 3 failures in each mine. Many of the failures occurred when roof bolting was relatively new and experimental work was being done to determine the applicability of roof-bolt installation. It was found during the experimental periods that, to support the roof properly with bolts, it was at times necessary to reduce the width of places, install additional bolts, or install longer bolts. It was also learned in other instances that places could be widened, that shorter bolts could be used, or that spacing of the bolts could be increased safely. It was also determined that roof bolting alone was not adequate under all conditions. In mines where the roof was structurally weak and the thickness of the vein precluded the use of longer bolts, it was necessary to adopt various combinations of roof bolting and timbering. Only a few of the total failures to date occurred in the immediate areas of the working faces, and the majority of falls were of roof that had been bolted and standing for periods ranging from a few weeks to several years. Many failures occurred when the mines were idle or when no one was at or near the immediate areas, and it is not known to what extent the roof worked or the amount of warning given before total collapse. Several failures occurred in the coal mines during working hours or when men were nearby and very little if any warning was given; however, in most instances a considerable amount of time elapsed - from a few hours to several days - from the time the roof was first detected working until it fell. Virtually all failures in the ore mines were preceded by audible warnings as the ground worked before total failure took place. The fact that the roof rocks of the ore mines are stronger, harder, and contain fewer slips and faults, and less fossiliferous material than are generally found in the coal mines probably accounts for the additional warning given. Most failures in the past were at crosscut and room-neck intersections and at wide places where additional area was exposed. Most of the failures were of roof that had been bolted in accordance with a predetermined plan, but because of changes in the physical features of the roof at local areas in which the strata contained faults, slip planes, rolls, angular joints, and vertical joints the bolting plans adopted were inadequate. Other failures of bolted roof throughout the coal and iron-ore mines were caused by one or more of the following conditions:

1. Bolting loose or broken roof and installing bolts in roof that had sagged.

2. Poor anchorage of bolts, caused by not driving the bolts over the wedges to refusal, the diameter of the holes too large, or the wedges too thin or both, anchoring in soft material, and drilling the bolt holes too deep for proper anchorage of the slit-and-wedge-type bolts.

3. Spans too wide for roof conditions and length of bolts used.

4. Bolting in roof that was unsuitable for roof bolts alone.

5. Bolts too short to extend through draw rock or faulty roof and be anchored in firm roof.

With the experience gained in detecting doubtful roof in 5 years of roof bolting, much has been done in preventing failures. In comparison to the amount of bolting done, failures are far fewer now than they were in the past. Failures of bolted roof that would have taken place in the past are now prevented by taking precautionary measures when heavy or faulty roof conditions are detected by installing additional bolts or longer bolts or both, or reinforcing the weak areas by timbering. Some roof falls still occur throughout the coal mines, but in the iron-ore mines they happen far less frequently. In fact, in one large operation that includes several ore mines, only one failure of bolted roof occurred in a 9-month period.

## ACCIDENTS

From the time roof bolting was introduced in May 1948 until May 1953, a 5-year period, there were 2 fatalities caused by failures of bolted roof, 1 each in a coal mine and an iron-ore mine. The first fatal accident occurred in a coal mine August 6, 1951, and the second accident occurred in an iron-ore mine March 28, 1952.

The failure in the coal mine happened near the working face of a room that had been driven about 32 feet in width to a depth of approximately 140 feet. The roof of the room was supported with slit-and-wedge-type bolts, 1 inch in diameter and 30 inches in length, installed vertically. The bolts were installed in sets of 7 across the room on approximately 4-foot centers both ways. A double row of posts, one row along each side of the panline, was used in conjunction with bolts primarily for warning purposes. The thickness of the coal bed limited the length of the bolts that could be installed to 30 inches. The failure extended from a point 14 feet outby the face for 83 feet, and the width varied from the full width of the room across the center of the fall to the ends for an average width of about 24 feet. The average thickness of the fall was about 4 feet. Except that the immediate strata contained some coal streaks, the area that failed consisted of a massive slip or slab of shale with no laminations. The roof rock that fell was in the shape of a double horseback at the outby end, flattening out gradually to the inby end and feather edging at both ends and along portions of both sides at the outby end. Where the strata separated the surface was slickensided. The only bolts that extended through the slip and anchored in solid roof were those that were located where the slip came to a feather edge. The accident was attributed to bolting unknown faulty roof in which the bolts gave very little support, and enough posts were not set to give ample warning of roof movement under such conditions.

The failure in the ore mine occurred along an entry at the intersection of a stope where a loading station was set up. The immediate roof at the loading station consisted of tough caprock (part ore and part rock). The caprock extended along the right side of the opening to an open end at variable distances from the right rib. The rock tapered from about 10 inches in thickness along the rib to about 6 inches inches in thickness along the open end. The main roof is hard sandstone. The roof of the immediate area was supported with both bolts and timbers where deemed necessary, but a standard pattern as to spacing was not followed. Wedge-type bolts 1 inch in diameter and 60 inches in length were installed vertically with individual bearing plates. That portion of the cap rock, measuring 8 feet wide by 10 feet long, which fell had been supported with 5 bolts. Four of the bolts were bent away from the rib and sheared at a point where the top of the cap rock and the main roof come together. The fifth bolt was bent and was pulled out of the hole where the rock fell. The shearing action on the bolts between the cap rock and main roof was caused by lateral movement of the cap rock away from the rib and the lateral movement of the main roof, if any, toward the rib. The total lateral movement measured 6 inches. The accident was caused by a failure of bolted roof in which lateral roof movements, owing to pillar extraction, sheared the bolts supporting the caprock roof.

During the 5 years there were no lost-time accidents in either the coal or iron-ore mines from failures of bolted roof. In the same period there were 22 lost-time accidents in the coal mines and 22 lost-time accidents in the iron-ore mines

Original from THE OHIO STATE UNIVERSITY

in which men were injured in connection with roof bolting. These lost-time accidents to the roof bolters were caused in various ways, the most common of which were:

1. Being struck by small pieces of roof rock falling from between the bolts during bolting and from rock falling while the roof is being scaled in preparing to roof-bolt.

2. Having hands or fingers caught between the roof and drilling equipment during drilling.

3. Being injured in various ways while handling and using bolting equipment and supplies, such as drill steel breaking, drill steel falling from bolt holes, and stoper drills out of control.

4. Eye injuries from particles of flying rock in collaring the bolt holes.

## CONCLUSIONS

Prevention of roof-fall accidents and increased tonnages generally obtained in roof-bolted areas are the chief benefits of roof bolting. Roof bolting not only reduces roof-fall accidents, but it also should be credited with preventing many other types of accidents that occur in various ways when timbering is used. Besides roof support, many benefits that do not show directly in statistics have been derived from this type of roof control. Face workmen can do a better job in preparing the working faces and cleaning up materials when not impeded by timbers; chances of timbers being knocked out by blasting and by moving equipment at the working faces and along haulageways are eliminated; more headroom is provided under low top where it would have been necessary to use cross collars; ventilation is benefited by not having airways cluttered up with timbers; there is additional clearance between ribs and moving equipment; and material is not as bulky to transport and handle.

Information relative to roof bolting in both the Alabama coal and iron-ore mines from the time roof bolting was introduced May 1, 1948, to May 1, 1953, and as of May 1, 1953, is shown by statistics in the following tables.

Data in table 1 deal with tonnages, the number of bolts used, the average tonnages mined per bolt, and the percent of total tonnages mined under roof bolts for the 5 years. The number of bolts (estimated) that were not used directly in connection with production, subtracted from the total number of bolts used gives the number of bolts which were used at the working faces directly in connection with production. The average tonnages per bolt times the number of bolts used at the working faces shows the total tonnages mined under bolts. The tonnages mined per bolt of the various coal mines ranged from 1.5 to 6.8 for an average of 4 tons per bolt, and the tonnage mined per bolt of the various ore mines ranged from 13.6 to 22.0 for an average of 20 tons of ore per bolt. From the above data are found the percentages of the total tonnages of coal and ore mined directly under roof bolts for the 5 years.

TABLE 1. - Tonnage and Roof-Bolt Data, 5 years, May 1, 1948 - May 1, 1953

| | Coal Mines | Ore Mines |
|---|---|---|
| Total tonnages mined underground, all mines ............. | 66,958,975 | 34,607,223 |
| Total number of bolts used ............................. | 3,261,200 | 1,277,700 |
| Number of bolts not used directly in connection with production ............................................ | 65,224 | 25,554 |
| Total number of bolts used directly in connection with production ............................................ | 3,195,976 | 1,252,246 |
| Average tonnages mined per bolt ........................ | 4 | 20 |
| Total tonnages mined under bolts ....................... | 12,783,904 | 25,044,920 |
| Percent of total tonnages mined under bolts ............ | 19 | 72 |

Data in table 2 deal with information as of May 1, 1953.

TABLE 2. - Tonnage and Roof-Bolt Data as of May 1, 1953.

| | Coal Mines | Ore Mines |
|---|---|---|
| Average daily total tonnages, all mines ................ | 49,536 | 28,000 |
| Average daily tonnages of all mines bolting ............ | 39,783 | 28,000 |
| Average daily tonnages mined under roof bolts .......... | 26,112 | 28,000 |
| Percent of total daily tonnages, all mines, mined under roof bolts ............................................ | 53 | 100 |
| Percent of daily tonnages of mines bolting ............. | 66 | 100 |

Comparison of the fatality rates per million tons of materials mined for the 5 years in the coal and iron-ore mines shown in table 3 shows clearly the advantages in roof bolting over timbering in preventing fatal roof-fall accidents.

TABLE 3. - Fatalities and Fatality Rates, 5 years, May 1, 1948 - May 1, 1953

| | Coal Mines | Ore Mines |
|---|---|---|
| Number of roof-fall fatalities: | | |
| Roof was not bolted ................................. | 48 | 7 |
| Roof was bolted ..................................... | 1 | 1 |
| Total all mines .................................. | 49 | 8 |
| Fatality rate per million tons: | | |
| All mines ........................................... | 0.732 | 0.231 |
| Under roof not bolted ............................... | 0.886 | 0.732 |
| Under bolted roof ................................... | 0.078 | 0.039 |

For additional comparison, the average rate of production per fatality for the 5 years, under bolted roof, under roof not bolted, and under roof either bolted or timbered is shown in table 4.

TABLE 4. - Analysis of roof-fall fatalities

| Mines | No. of fatalities |  | Million tons mined per fatality |  |
|---|---|---|---|---|
|  | Coal | Ore | Coal | Ore |
| Roof was bolted ..... ................ | 1 | 1 | 12,783,904 | 25,044,920 |
| Roof was not bolted ................. | 48 | 7 | 1,128,648 | 1,366,043 |
| Total ........................ | 49 | 8 | 1,366,509 | 4,325,903 |

Comparing the average rates of production per fatality between bolted roof and timbered roof shows an improvement of bolted roof over timbered roof of 91.9 percent in the coal mines and 94.8 percent in the ore mines. Assuming that, if no roof had been bolted in either the coal or ore mines for the 5 years and that the same rates for timbered roof had continued there would have been 59 fatalities instead of 48 in the coal mines and 29 fatalities instead of 7 in the ore mines. By these estimates roof bolting prevented 33 fatalities from falls of roof, 11 in coal mines and 22 in the ore mines. The greatest improvement was in the ore mines, owing to the fact that virtually 100 percent of the production had come from roof-bolted areas over a period of several years.

It must not be concluded that roof bolting is a cure for all roof conditions in the mining industries In many instances and at various locations it is at times necessary to supplement bolting by timbering, and in other instances it is still necessary to revert to steel timbering or concrete piers at wide intersections to reinforce heavy roof. Most of the roof-fall fatalities in the coal mines of the United States occur at the working faces from falls of roof that do not average over 12 inches in thickness. These accidents are generally caused from inadequate timbering or no support at all. The lack of adequate timbering usually is due to the hindrance presented when timbers are set in the face areas. Virtually all accidents of this type could be prevented if roof bolting was practiced, even though the bolts installed were only 18 inches in length and supplemented with proper timbering to suit the conditions encountered.